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## ARTICLE VII.

# THE CRETACEOUS AND TERTIARY GEOLOGY OF THE SERGIPE- ALAGOAS<sup>A</sup> BASIN OF BRAZIL.

BY JOHN C. BRANNER, PH.D.,

PROFESSOR OF GEOLOGY IN THE UNIVERSITY OF INDIANA,

STATE GEOLOGIST OF ARKANSAS, FORMERLY ASSISTANT GEOLOGIST OF THE IMPERIAL GEOLOGICAL SURVEY OF BRAZIL.

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### PART I.

#### *Prefatory Notes.*

In the years 1875 and 1876, while assistant geologist on the Imperial Geological Survey of Brazil ("A Comissão Geologica do Imperio do Brazil"), I spent several months in examining the geology of the provinces of Pernambuco, Alagoas and Sergipe. The work done was but little more than a hasty reconnaissance, made without any maps whatever, even of the rudest kind, and without either time, instruments or appropriation for making them.

I cannot therefore refrain from expressing my reticence in regard to publishing what little I know concerning the geology of the region treated of in the present paper. Although the work of the Imperial Survey in the region was all that could have been accomplished in the time occupied, and though it was much more extensive than any done prior to my visit, it was far from satisfactory.

Three other reasons have caused this delay in the publication of my observations. First, I hoped that the Brazilian Government would see fit to have the results of the Survey's work published more in detail than is possible here. This has not only never been done, but until the publication by that government of Dr. C. A. White's important "Contributions to the Palaeontology of Brazil" none of the results have been brought out, except as the former members have found time to prepare brief papers and publish them wherever an opportunity offered. Even in the case of Dr.

White's paper, the delay in its printing was very tedious, the report having been issued four years after the manuscripts and drawings were prepared. Second, I have delayed on account of the incompleteness of my observations, and because of my hesitation lest I should add to that class of writings upon Brazilian geology which is made up, to so great an extent, of generalizations based upon very limited observations. A third reason for delay has been the somewhat vague hope that I might yet have an opportunity of completing my studies. As time goes on, however, the probability of my being able to revisit the provinces of Sergipe and Alagôas appears to lessen rather than increase. Since my exploration in those provinces I have returned to Brazil three times, but as Aracajú and Penedo are small ports off the principal lines of travel, visited only by sailing vessels and small coasting steamers from Bahia or Pernambuco, I have never found it possible to make further examination of the geology of this interesting region. It is hoped, however, that these notes may be of service to those who may hereafter undertake to add to or finish the work begun.

Much of this paper must be of a statistical nature, for the relation of facts to each other, except in a general way, is not understood, and I do not deem it necessary or discreet to enter upon the discussion of these relations in detail until more thorough information is had of the region in question.

The sketch map accompanying this paper makes little pretension to accuracy and is only introduced for the purpose of giving some idea of the geography of the region under discussion.

The defects of the records are quite evident to myself, but in spite of such defects, I am confident that the facts presented will be useful to those who may hereafter have occasion to do work in this region. As far as I am aware, no geological work has been done here since 1876, if I except the trip made up the Rio São Francisco by Mr. Derby, the geologic results of which were published in the Archivos do Museu Nacional, Vol. IV, p. 87 et seq., but this paper, while it treats somewhat of the mesozoic geology of the region, does not appear to represent any new work thereon. What I have to say in this paper is upon my own authority, except where others are quoted and credit given.

I should be remiss in a most pleasant duty did I not refer here to the universal encouragement which the naturalist, traveler, or stranger meets at the hands of Brazilians in all parts of that country, and especially in the provinces of Sergipe and Alagôas. The poorest laborer kindly and politely urges you to "make no ceremony" about sharing his humble fare, while the richest gentleman assures you and makes you feel that his house and his servants are "yours" indeed. I am under especial

obligations to Robert Brown, Esq., H. B. M.'s Consul at Maroim, for assistance in the prosecution of my work in the province of Sergipe.

#### OUTLINES OF THE BRAZILIAN CRETACEOUS.

That the relations of the Sergipe-Alagôas basin to the other more or less similar deposits of the Brazilian coast may be better understood, I give here briefly the prominent features of the cretaceous geology of the several basins along the coast as far as they are known.

I use the term "basin," however, in speaking of the geology of the provinces of Sergipe and Alagôas partly to separate the locality geographically from others of a more or less similar character north and south, and partly because it seems to have been one of the separate wide-mouthed bays or indentations—mere curves of the shore line—which characterized this coast in cretaceous times.

The exposures of mesozoic rocks along and near the Brazilian coast point to the probability that this portion of the coast line of the Atlantic was, during cretaceous times, but slightly different from that of the present day.

The accompanying small map of Brazil will give an idea of the geographical relations of the known cretaceous exposures to each other, and will suggest, at the same time, the form of the coast at the time of their deposition.

The most southerly exposures of cretaceous rocks thus far discovered in Brazil are upon the island of São Francisco in the province of Sta. Catherina. Others occur along the coast at the Abrolhos, at Bahia, throughout the extension of the Sergipe-Alagôas basin from Estancia to Rio Formozo in the province of Pernambuco, at Olinda, Maria Farinha and on the island of Itamaricá in the province of Pernambuco, at Parabyha in the province of this name, on the Rio Mossoro in Rio Grande do Norte, and about Crato in Ceará, while the most northerly exposure known along the coast is found on Rio Piábas, province of Pará. More detailed descriptions of these several basins and localities will be given at the end of the description and discussion of the Sergipe-Alagôas basin.

#### PREVIOUS WORK.

A glance at the annotated bibliography of the subject given at the end of this paper will show that almost no work was done on the geology of the Sergipe-Alagôas basin prior to 1875.

In 1838, George Gardner, the English botanist, during a short voyage on the São Francisco made in pursuit of his botanical studies, made a few notes upon the

geology of the region. These notes, however, were so few as not to be worth mentioning, except for the fact that he afterwards made some valuable observations upon the mesozoic geology of Ceará, and expressed the opinion that the Penedo sandstones were "identical with those from the upper sandstones of Crato."

Charles Darwin, in his "Observations," makes references to the mesozoic geology of Pernambuco and Bahia, but he did not visit the coast between those places.

In 1866, Prof. Ch. Fred. Hartt touched at Aracajú, Maroim, and Penedo, and gives the results of his observations in his "Geology and Physical Geography of Brazil." He obtained a small collection of fossils at Maroim, but one of sufficient importance to throw light upon the age of the rocks. He noted exposures at Sapucary (by him called Sapucaby), Maroim, and through Mr. Laué, who then lived at Maroim, obtained specimens of *Natica*. The cephalopods of this collection were described by Prof. Alpheus Hyatt, and the descriptions published in Hartt's "Geology and Physical Geography of Brazil," p. 385. No explorations, whatever, had been carried on inland, or even along the navigable parts of the streams. The facts brought out in regard to the Sergipe-Alagôas region by Hartt are substantially as follows:

*First.* Reporting the following exposures: Estancia red sandstones, and the limestones of São Gonçalo, Sapucary, Maroim, Villa Nova, Penedo, Morro de Chaves.

*Second.* Reference of the Maroim beds to the upper cretaceous, it is presumed, upon the paleontologic evidence of Prof. Hyatt's descriptions of the cephalopods. The descriptions of these fossils is the only work known to have been done upon the fossils of the region up to that time. Prof. Hyatt in his paper expressed no opinion concerning the age of the beds, but what appear to be Hartt's field labels are given as "from the cretaceous of Maroim." Such was our knowledge of the geology of the region here treated of when the writer visited it as a member of the *Comissão Geologica do Brasil* in 1876.

#### THE GEOLOGIC IMPORTANCE OF THE SERGIPE-ALAGÔAS REGION.

Much of the Brazilian coast is very old geologically, no sedimentary beds to indicate the changes through which this part of the continent has passed intervening between the ocean and the granites and gneisses which are referred to the archæan. Along a considerable portion of the north-eastern coast, especially from Cape Sto. Agostinho to Parahyba do Norte, soft sedimentary beds, provisionally referred to the tertiary, are exposed here and there in abrupt bluffs which are being cut away by the ocean. These rocks, however, although well exposed, have as yet yielded no fossils,

and do not, of themselves, throw much light upon the changes through which the coast has passed. Nowhere along the Brazilian coast from the frontier of Uruguay to Cape North are any fossiliferous paleozoic beds exposed, and there are but few places in which a section from the ocean to the archæan rocks would pass through anything more than recent deposits and the horizontal tertiary beds referred to above.

In no place along the whole coast, however, can a wider and deeper section be found, or one in which the rocks afford a more complete history of the changes through which this part of the continent has passed from paleozoic times up to the present than the basin cut by the Rios São Francisco and Sergipe, and which lies within the two provinces of Sergipe and Alagôas. The importance of this region is due to

1. The representation of a geologic range unusual in Brazil.
2. The rich fossiliferous nature of many of the beds.
3. The accessibility of good exposure across the entire section.

Doubtless one of the chief reasons that these two provinces are not better known geologically, is the fact that they are not on the principal line of travel between Europe and South America, and are, therefore, more or less inaccessible, and if the geological importance of the region has not been recognized, it must be attributed to the fact that hitherto nothing, or next to nothing, has been known of it.

With the exception of a canoe voyage by Gardner along the Rio São Francisco to Piranhas in 1837, and a very brief visit to Maroim by Prof. Hartt in the year 1865, none of the writers upon the geology of Brazil, prior to the work done by the Imperial Geological Survey, ever visited the Sergipe-Alagôas region, and even those few earlier writers have but little to say of the geology of this section of the country.

I am of the opinion that the key to future successful geologic work in Brazil lies in the careful study and comprehension of some such typical region as that comprised in the provinces of Sergipe and Alagôas. The Bahia basin is an interesting one, and, as Dr. White has pointed out in his recently published "Contributions to the Paleontology of Brazil," faunally more interesting perhaps than that of Sergipe-Alagôas, but the Bahia basin being of lacustrine origin is *sui generis*, as far as the mesozoic geology of Brazil is understood.\* The Sergipe-Alagôas beds on the other hand are marine, the rocks above the archæan vary lithologically and faunally, and are more or less exposed across the whole width of the region from the ocean to their inland margins at the base of the Serra d'Itabaiána, while at this latter locality, the lowest of the sedimentary beds are well exposed where the serra is cut through

\* Pissis, in his memoir published by the French Academy, p. 402, says that the tertiary beds of the interior of Brazil, and lying between the coast range and the Serra de Mantiqueira, are lacustrine.

by the Rio Sergipe, and their relations to each other and to the underlying archæan rocks are distinctly shown.

Aside from its purely geologic interest and importance, there is, perhaps, no part of the coast north of Bahia so fertile, the soil being of the black quality known here as *massapé* and derived from the decomposition of certain limestones and of organic matter. Wherever the tertiary beds have been eroded away exposing the underlying cretaceous rocks, the decaying of these calcareous beds has produced a soil, which, in spite of indifferent cultivation, yields abundant crops of sugar-cane, cotton, mandioca, etc. Although the cane-fields upon some of the cretaceous soils have not been re-planted for thirty years, they still produce abundantly.

#### TOPOGRAPHIC FEATURES AND VEGETATION.

The topography of the Sergipe-Alagôas region may be divided into the following five types:

- I. The low, flat lands of quaternary and recent origin, immediately bordering the coast and streams.
- II. The tertiary plateaux.
- III. The cretaceous hills.
- IV. The serras, or paleozoic region.
- V. The trans-serra, or archæan region.

I. *The low, flat lands.*—In some places these flat lands are made up of sand barrens, or they are covered with sand dunes; in others they are low grounds flooded at high tide, and usually form what are known as mangues, or mangrove swamps, bordering the estuaries. This type, or rather the mangrove part of it, is not confined to the immediate neighborhood of the ocean, but extends inland as far as the tides are felt, sometimes for many miles, and in general outline has a dendritic form. On the Cotinguiba it reaches the town of Larangeiras, on the Sergipe that of Riachuelo, and on the Maroim branch it reaches the city of that name.

The vegetation of this belt is a characteristic one. The mangues are in no particular different from those to be found along the whole Brazilian coast, except, perhaps, in the blackness of the mud where it is derived from the decomposition of the calcareous cretaceous rocks and organic matter. In places these mangues broaden out until they are from two to five miles wide, and in other places their outer margins approach the streams where the latter are encroached upon by the hills. Thus they are at once the characteristic feature of a well-defined topographic type, an important geologic agent, and an interesting form of vegetation. When the mangrove plants

(*Laguncularia racemosa* Gaert. and *Avicennia tomentosa* Lin.) have reached maturity, the mangues (swamps) are very nearly, if not quite, impenetrable, and the rapidity with which old vegetation decays and young vegetation seizes upon new and reclaimed lands in the tropics, make them a more powerful agent in the accumulation of sediment and organic matter than are the mangrove swamps of Florida.

In its predominant features the belt of sandy lands and dunes does not differ in any marked degree from that of any sandy coast. The sands drift with the winds, and the configuration seen at one time is entirely obliterated a few weeks or a month later.

Not infrequently these dunes are driven into the edges of the thick forests which grow upon the adjacent topographic belt, but beyond this margin they cannot penetrate far. The effect of the blown sand upon the vegetation in such cases is very marked. The flying grains soon bruise and kill the buds and tender leaves and ultimately a peculiarly rounded, lobed and closely cropped appearance is given to the windward margins of the forests. Although these dunes do not assume the proportions in this part of the empire that they do in some of the more northern provinces,\* the entire coast of Sergipe and a large portion of that of Alagôas are covered by a sandy belt which varies in width from five hundred feet to two or three miles.

In some places the dunes predominate, the shifting sands often encroaching upon and burying mangrove swamps and the underbrush of adjacent forests, while in others they form broad, flat glades with a sparse and characteristic flora of cajús, cacti, etc. From the Barra de Japaratúba to the mouth of the Rio Cotinguiba the unbroken line of dunes thrown up by the prevailing east winds has here arrested the drainage and turned it westward through the Rio Pomonga which flows into the Cotinguiba just north of Aracajú.† To the south of the Cotinguiba these dunes often assume extraordinary proportions.‡

The vegetation of the sandy belt is necessarily sparse at the best. Wherever the sand is constantly shifting, as it is in the newer portions of the belt, vegetation has no opportunity to take root. In those portions, however, in which, for any reason, the sands assume more or less stability, certain drought-resisting forms of vegeta-

\* There has been some speculation regarding the origin of these vast accumulations of sand along the Brazilian coast, and especially about Cape St. Roque, M. de Jonnes holding that they are brought to these shores by the equatorial current (see Ceará, by Pompeo de Souza, p. 13), while Dr. Capanema holds that they come from the Serra do Araripe. Whatever may be the origin of the sands north of Parahyba, south of that point they are derived directly from the rapid cutting away by the ocean of the soft tertiary beds.

† See also Relatório da Comissão Hidráulica do Rio São Francisco, by W. Milnor Roberts, Rio de Janeiro, 1880, p. 4.

‡ See Geology and Physical Geography of Brazil, by Chas. F. Hartt, p. 380.

tion quickly take root and flourish upon it. The cacti are naturally in this list, and I have found one species of fern here, while the cajú tree, one of the blessings of the country, seems to reach its highest development in this parched and arid soil.

II. *The tertiary plateaux.*—This and the succeeding types can best be understood by anticipating somewhat the succession of geologic events in this region. The cretaceous formation was here overlain by not less than two hundred feet of horizontal, particolored beds of soft sandstones and clay. Since the emergence of the region from the ocean, the overlying tertiary beds have been extensively eroded. Where the tertiary beds have not been entirely washed away, flat-topped, angular-shouldered hills still cover the cretaceous beds, and form the topographic type under consideration. These plateaux are not confined to any particular belt, but may be found anywhere between the ocean and the serras. The tertiary soils are, as a rule, very sterile, their sterility being due partly and directly to the character of the soil and partly to its tendency to wash, and its inability to receive and retain sufficient moisture to support vegetation. The natural growth of vegetation upon this soil is strikingly poor, and this region of plateaux is generally covered with a sparse and stunted growth of forest and sedge, while the land is extremely barren, and unfit for cultivation. It is also seriously affected by droughts. Types of this topography occur between Maroim and São Christovão.

III. *The cretaceous hills.*—From what has been said it may be anticipated that the region of the third type owes its existence to the erosion of the tertiary beds, and the consequent uncovering of the underlying cretaceous. While this is true in the main, there are certain elevations in this basin which I am disposed to regard as never having been covered by the tertiary deposits, certainly not to any considerable thickness. In making a voyage between Aracajú and the mouth of the Rio São Francisco, one may see a range of cretaceous hills lying south of the river and well inland, though disconnected with the higher lands of the serras. This range of hills stands at a higher elevation than any of the tertiary hills on either side of it, and for reasons given further on, it is not believed that the erosion from the summits of some of the tertiary hills has been very extensive.

The region on the whole is a broken one, the hills being more or less rounded as a rule, though a few of them have abrupt faces toward the north and west. Although the topography of this region is a characteristic one, its value for the purposes of geologic reconnaissance is somewhat impaired by the presence of the overlying tertiary beds in a great many localities. This type characterizes the region between Aracajú and Itabaiána and between Larangeiras and the serras. The vegetation is large and abundant, and within this belt one may often find excellent examples of the

ideal tropical forests having an undergrowth well-nigh impenetrable and trees whose enormous trunks reach heights almost incredible.

IV. *The serras, or the paleozoic region.*—This type lies to the north and west of the mesozoic region, and forms a well-defined, natural boundary between it and the archæan region which lies farther inland. In the province of Alagôas this border is formed by the Serra de Marába, which, in its continuation to the south-west, is called the Serra d'Itabaiána, and still farther to the south Cajahyba. This entire range is the monoclinal remains of the eroded landward margin of the beds here exposed. The rocks dip to the east and south-east at an angle of from fifteen to twenty degrees, and underlie the cretaceous and other beds between the serra and the ocean. For the most part these serras are covered with forests nearly to their summits.

V. *The trans-serra or archæan region.*—The topography of this region is an exceedingly varied one; now hilly, now mountainous, and now spread out in gently undulating plains. In some places it is notoriously sterile and is covered, for the most part, with a sparse growth of stunted timber, while in others it is more fertile, and produces a more vigorous forest. But little time was devoted to the geology of the archæan region.

#### THE SERGIPE-ALAGÔAS BASIN.

It will be seen in the resumé of what we know of the mesozoic geology of Brazil that too little is known of the exact limits of the cretaceous basins along the north-eastern coast of South America to permit a single one of them being clearly and satisfactorily outlined. More work has been done on the Bahia basin than upon any other one of the number, but of even this the limits are not known. For the better understanding of the region, it is deemed best, however, to give such facts as are available in roughly outlining the Sergipe-Alagôas basin, before giving the details of local geology.

The Bahia beds being of lacustrine origin, while those to the north are of marine origin, it may safely be assumed that these two basins were independent of each other at the time of the deposition of their beds. The most north-easterly point at which the Bahia cretaceous is known to occur is near Catú in the province of Bahia, and the most southerly point at which the marine cretaceous beds of the Sergipe-Alagôas basin have been observed, is at and about Estancia, in the province of Sergipe. The southern margin of this basin must, therefore, be to the south of this place. The rapids in the Rio Real, known as Passagem das Pedras, suggests the possibility of the red sandstones, which make the cataracts at Estancia, crossing the Rio Real at Passagem.

To the north of Estancia no exposures are known until one approaches the Pedra da Cajahyba which forms a part of the Itabaiána range of mountains.\* From this part of the province to the Rio São Francisco near Propriá the mesozoic basin is bordered on the landwards side by the eastward extension of this same range of mountains. In the province of Alagôas, the Serra de Marába forms the north-west boundary, and by its trend leads one to suppose that this north-west margin continues for some distance in a line parallel to the coast.

Just where this basin ends to the north-east, and indeed whether it ends at all, either within the borders of Alagôas, or of Pernambuco even, is not known. The geology along the coast between Maceio and Rio Formozo has never been examined, and it is possible that this basin comes to an end between these two points. The writer feels warranted in the opinion—though it is only an opinion—that Porto Calvo is in the Sergipe-Alagôas basin, and it is possible that its beds are exposed at Rio Formozo. An examination of the relations of the archæan rocks and what was at the time supposed to be the tertiary beds at and near the mouth of the Rio Formozo in the province of Pernambuco, does not definitely settle the question as to whether or not the cretaceous beds continue to the north of this point. The beds seen at Rio Formozo lie unconformably against the crystalline rocks, but it is not clear whether the beds supposed, at that time, to belong to the tertiary do really belong to that period. They are, in general appearance, certainly unlike any tertiary beds seen elsewhere in Brazil, being made up of alternate beds of conglomerate, clay, chalk and chalk with flint nodules.

If then the cretaceous beds are continued from Alagôas and extend to the north of Rio Formozo, it is possible that they underlie the tertiary about Cape Sto. Agostinho, and are continued on the landward side of that cape, underlie Pernambuco, crop out at Olinda, Maria Farinha, Iguarassú, the island of Itamaricá, and may even connect with the mesozoic beds exposed at Parahyba do Norte and further north.

#### LOCAL DETAILS.

The present discussion of the Sergipe-Alagôas basin must be based upon facts gathered for the most part in the vicinity of Maroim, the Serra d'Itabaiána, along the Rio São Francisco and the Serra de Marába.

\* The beds of this range which I have referred to the paleozoic probably underlie the cretaceous beds of all this part of the coast. In a letter to me, in answer to one making inquiry regarding the nature of the region traversed by him from Bahia to Sergipe, Mr. Derby writes: "In the trip across Bahia and Sergipe, I found a series of shales and sandstones in the region between the Rio Real and Itabaiána which is most probably the same seen in the mountains. So far as I could see, there is nothing between that and the gneiss."



The Serra of Itabaiana from the North.

These and the other localities mentioned below are the only ones examined that are judged to be of sufficient importance, or at which sufficiently valuable observations were made, to be worthy of mention here. Hundreds of places were visited in this region at which poor exposures of cretaceous rocks were found, but they could throw no additional light upon the geologic structure of the region without the use of more trustworthy methods of work than it was possible to employ at the time.

Inasmuch as the tertiary geology of this region is the subject of the second part of the present paper, the beds of this series are not discussed in this place.

In view of its general importance and the light it throws upon the structure of the entire region the details of the Itabaiána exposures will be taken up first.

*Itabaiána*.—The best section seen of the rocks underlying the mesozoic beds are exposed where the Rio Sergipe cuts through the range of mountains of which Itabaiána forms a part. Here the crystalline rocks are exposed on the inland side of the range, and in the gap cut by the river, the unconformable contact between these and the sedimentary beds, which are presumed to be paleozoic, is plainly seen. The conglomerates, false bedded sandstones, and shales which make up the great body of the section, have been so metamorphosed that the prospect for finding fossils in them is not very encouraging.

The sandstones are almost all changed to exceedingly hard, glassy quartzites, which by much jointing have broken into smooth-sided rhomboidal blocks. Following down the stream one ascends geologically, and finds these quartzites and conglomerates the principal rocks exposed, while those of shale, in which one most hopefully looks for fossils, are but poorly exposed or entirely covered with talus from the overhanging ledges. These beds have a pretty uniform dip of 15–20° to the south-east. Along the escarpment of the north face of the mountain range the upturned edges of the uppermost beds are partly exposed, while all the lower ones are covered with talus which stands at as high an angle as possible. In this talus large fragments of shale, such as was not seen *in situ* were examined for fossils, but without success.

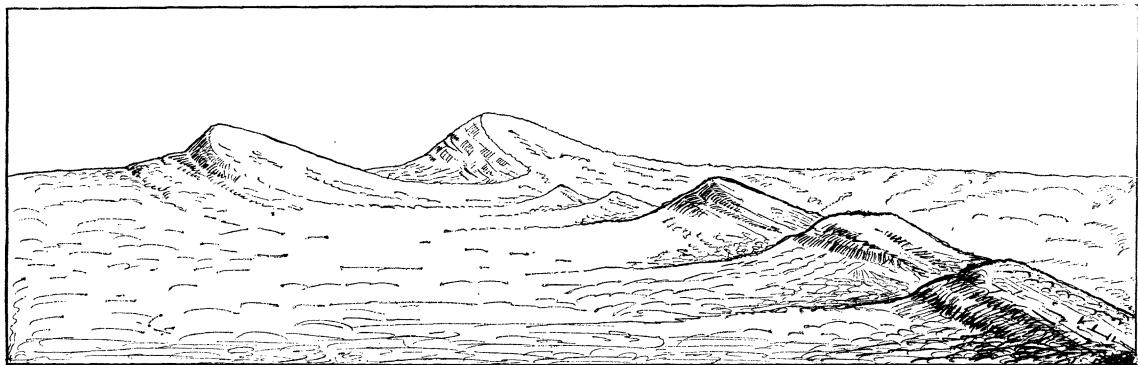
The brief time spent in examining the rocks of this section for paleontologic evidence of their age was very insufficient, and it is altogether probable that careful detailed examination of these beds will yet furnish the desired evidence.

From the top of Itabaiána the structure of this range of mountains and its geologic relations to the regions on either side of it are quite evident. The Itabaiána peak is at the base of a curve in the range which continues to the right, as one faces the ocean, towards the west and south-west, while to the left it extends to the north and north-west. About fifteen miles to the north the range turns eastward and is next

seen prominently on the Alagôas side of the Rio São Francisco, where it is known as the Serra de Marába. To the south-west different portions of the ranges are known by different names, the section next to Itabaiána being called the Serra Comprida, and that next the Cajahyba. It is evident at a glance that this range of hills bears the same relation throughout to the general Sergipe-Alagôas basin as the Itabaiána beds bear to those lying immediately between them and the ocean.\*

The section across the region given below shows the general relations of the various beds.

The following sketch looking north-east from the top of Itabaiána, shows the



Looking north-east from Itabaiána.

continuation of the range in a line of detached peaks, the rocks of which all dip oceanward beneath the mesozoic beds. Fig. B. is a sketch from near the south-east

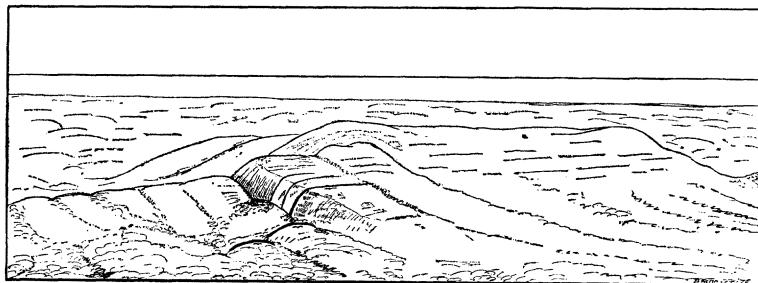


Fig. B. Serra Comprida from Itabaiána.

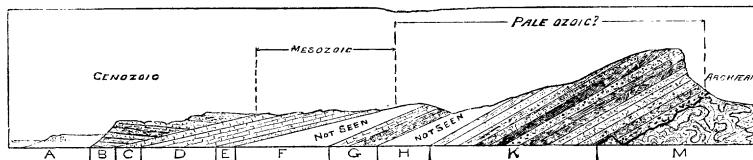
end of Itabaiána peak, looking toward the south-east. The beds of the Serra Comprida are seen from the inland side, somewhat, and appear to be faulted.

#### *The Itabaiána Section.*

The accompanying section across the Sergipe-Alagôas basin is represented as being drawn from the archæan region north of the Serra, through Itabaiána, Maroim,

\* See note by Mr. Derby, on p. 378.

and Sto. Amaro to the sea. No attempt is made to represent relative thicknesses accurately, for no measurements have been made that will render this possible.



Section across the Sergipe-Alagôas basin.

Beginning at the base of the section, M represents the crystalline rocks of the archæan, here composed of beautiful greenish gneisses containing amethysts and yellow mica. At the point of contact the surface is uneven but hard and rounded as if water worn, and the conglomerates of the lowest of the paleozoic beds lie unconformably upon it. The gneisses at this place dip to the north-west though much crumpled in places. The same rocks when exposed away from the line of contact are soft and deeply decayed.

The lowest bed of K is a coarse and very hard conglomerate made up largely of fragments from the underlying gneiss. The next bed above is of coarse sand and pebbles, false bedded, followed by sandstone of varying degrees of coarseness. The pebbles in this bed are of all sizes up to that of one's fist, and vary in color from the white of milky quartz to the green of the underlying gneiss from which the latter are apparently derived. Next follow very hard sandstones with ripple marks, then fine, fine-grained sandstone. This is succeeded by fine-grained micaceous slaty rock with ripple marks, then very hard conglomerate followed by solid fine-grained slate, and coarse sandstone with micaceous bands.

These beds are all exceedingly hard, the sandstones being usually in the form of jointed and strongly false-bedded glassy quartzites. They have a uniform dip of from  $15^{\circ}$  to  $20^{\circ}$  to the south-east.

Of the thickness or importance of the rocks between the beds just mentioned and the next observed, nothing is known. On the sides of the hills immediately east of Itabaiána a series of slates, shales and sandstones were seen, but it was too imperfectly exposed to admit of a complete section being made, or of connecting such a section directly with that in the Rio Sergipe gap. On the part of the mountain east of the river the rocks dip south and south-east. The next overlying beds seen are limestones exposed on the stream between Itabaiána and Serra Comprida. Where they were examined they are considerably disturbed, very compact, and traversed by small veins of white quartz. In general appearance these rocks resemble the mountain limestones of England, but no fossils were found in them.

It is presumed that these limestones are included in the paleozoic beds which extend still higher. There is another break in the section here caused by the impossibility of observing the sequence of the overlying beds.

The next rocks seen, and of which the stratigraphic relations are known, are the mesozoic sandstones found in the hills at Engenhos Araçá and Pamonha, and which appear to dip gently to the north-west, that is, in the direction of the serra.\* This dip necessitates at least one syncline between this place and the mountains. Above these follow various beds of sandstone and limestone which are described more in detail elsewhere, all of which appear to belong to the cretaceous, with certain exceptional facies referred to in speaking of the age and correlation of the mesozoic Brazilian beds.

The cretaceous beds are somewhat disturbed, and some of them slightly metamorphosed. They are richly fossiliferous in places, and have furnished the interesting series of fossils described by Dr. White in his "Contributions to the Paleontology of Brazil."

The horizontal tertiary beds (B) which overlie these do not end along a well-defined line as one might infer from the section, but seem to have covered at one time almost all the mesozoic rocks, and to have been largely removed by denudation, leaving shoulders here and there, some of them but a few hundred feet and some of them miles in width. These beds are horizontal as far as the unaided eye can determine, non-fossiliferous, and are made up of particolored alternating strata of clays and sands, with here and there calcareous bands and concretions.

The last beds are those of quaternary and recent times which lie against the tertiary, cretaceous, paleozoic or archæan as the case may be.

*Recapitulation.—Explanation of the section:*

M. Archæan, (?) schists.

K. Conglomerates, sandstones and shales of the Itabaiána series, partially metamorphosed.

H. Not seen.

G. Limestones and shales.

F. Not seen.

E. Sandstones of Pamonha and Araçá.

D. Oolitic limestones and sandstones.

C. Chalky beds of Sapucary, Andorinhas, etc.

B. Horizontal tertiary sandstones and clays.

A. Quaternary and recent.

\* The fossils from these beds are referred to in Dr. White's work as coming from "Pamona," which should read Pamonha.

## EXPOSURES ABOUT MAROIM.

Quarries have been opened in many places in and about Maroim from which stone has been obtained for building walls and houses and for paving the streets. One of these quarries on the western side of the town is known as the *pedreira de Gambarobe*. The rock at this quarry is a brownish gray limestone, more or less oolitic, and contains some fossils, though the shells are usually broken and difficult of extraction. Lamellibranchs, cephalopods, decapod crustaceans, echinoderms, and occasionally very large gasteropods are found by the quarrymen. Many bits of fossil wood are also found here, but all in a charred condition.

On the eastern outskirts of the town, and lying more or less in it, at a place known as Aroeira are several old, abandoned quarries in calcareous sandstones. These beds contain many fossils, but the rocks are too hard to allow them to be taken out in good condition. The dip here is generally toward the east at a low angle. The fossils described by Dr. White from the Riacho de Aroeira are all from a small exposure in the bed of a wet-weather stream to the north-west of the quarries. At this place the rocks are more sandy than at the quarries referred to, and sometimes are hard as quartzites. They lie directly beneath the beds exposed at the quarries of Aroeira and dip to the S.  $80^{\circ}$  E., at an angle of six degrees. In the lowest part of the bed are fragments of the softer yellow rock which lies at a lower geologic level, forming, with the sand, a kind of conglomerate.

*Lastro.*

The richest locality for fossils found in the vicinity of Maroim is one known as the Lastro, about two miles down the river from the town, on the east side of the stream, and just south of the Engenho da Praia. From this engenho the exposures continue for more than three miles along the hills that border the stream on the east.

The fossils described by Dr. White from this locality come from the border of the mangue along the first three-quarters of a mile below the engenho. In this distance the rocks furnishing the fossils are mostly soft, decaying, cream colored to brown, oolitic limestones, which, by disintegration, have left the fossils free. In places the small rock fragments are so full of echinoderms that they can be picked out like walnuts from their hulls. In some cases the material of these fossils is changed to pure calcium carbonate, while in others the more compact beds of limestone have the fossils silicified so that they can be perfectly removed by the use of acid to dissolve the limestone.

The weathering out of the fossils at this place is hastened by the tides which

alternately cover and expose them to the air and sunshine. These same beds are exposed also on the opposite side of the river at a place called Jaque, where the stone was formerly quarried at low tide. Here, however, the rocks are harder than those at the Lastro exposure, the fossil fauna being the same.

The rocks at Jaque are oolitic, of a light-brown color near the surface, but where they have been blasted, or their interior parts are unaffected by weathering, they have a bluish-gray color.

Rocks similar to those found at the Lastro and Jaque occur from two to three miles further down on the west side of the stream. Here too the black flints which seem to have weathered from some limestone beds are widely scattered. The beds from which the flints have been derived overlie the oolitic rocks exposed at Lastro and Jaque. On the east side of the stream the rocks overlying the oolitic beds are soft limestones such as are exposed about Porto da Rede. On the west side the soft limestone beds are more or less flexed.

The fossils most abundant at the Lastro are conchifers, cephalopods and echinoids. There were found here sixteen species of conchifers, of which number ten are new to science; nine species of cephalopods, six of which are new; ten species of echinoids, nine of which are new. Gasteropods are remarkably scarce, but two species having been found here, both of which are new.

#### *Pedreira de João Pereira.*<sup>\*</sup>

This quarry is about two miles east of Maroim. The rock is a soft, cream-colored to yellow, oolitic limestone, affording many imperfect specimens of cephalopods. The rock is so soft that it is quarried in blocks by cutting trenches in it with picks. The fossils are bivalves and cephalopods. Three species of the former and three of the latter have been found here, all of which are new to science. The beds have a southerly dip.

#### *Garajáu.*

This locality is immediately north of the town of Maroim, and is interesting as containing the rocks from which one of the conchifers described by Dr. White as of jurassic aspect (*Aucella brasiliensis*) was obtained. Most of the fossils obtained here are cephalopods (*Ammonites hopkinsi*) and were broken from compact limestone blocks where they had been separated by disintegration from the main beds, which crop out here and there about the fields. These beds overlie those of Aroeira, Lastro, Jaque, Gambarobe, etc., all of which are oolitic.

\* This locality is wrongly given in Dr. White's Paleontology as João Ferreira in some places, while in others it has the correct spelling.

*Jacuruna.*

At Jacuruna, a short distance north-east of Maroim along the *estrada real* leading to the village of Rosario, is an exposure of oolitic limestones containing a few fossils. To the west of the Ponte de Sabão bridge, is a hill having outcrops of similar rock on either side. An exposure of limestone passes east and west through the village of Rosario. In one place where this stone is quarried, a bed thirty-five feet in thickness is exposed. The rock is oolitic and in lithologic characters strongly resembles that of the Gambarobe quarry in Maroim. The uppermost ten feet forms a massive bed. These beds dip at an angle of twenty degrees S.  $45^{\circ}$  E. (direction estimated). Between this point and Campo Redondo the country is low, these cretaceous rocks and their hills forming the southern boundary of the valley, while a range of tertiary hills bounds it on the north. Soft, cream-colored, cretaceous limestones underlie these tertiary hills as was shown in the pits excavated north of Engenho Campo Redondo in a search for coal or gold. From one of these pits, ten feet deep, a few fragments of fossils were obtained, one of which, *Camptonectes placitus* White, is described in Dr. White's "Paleontology of Brazil."

*Coqueiro.*

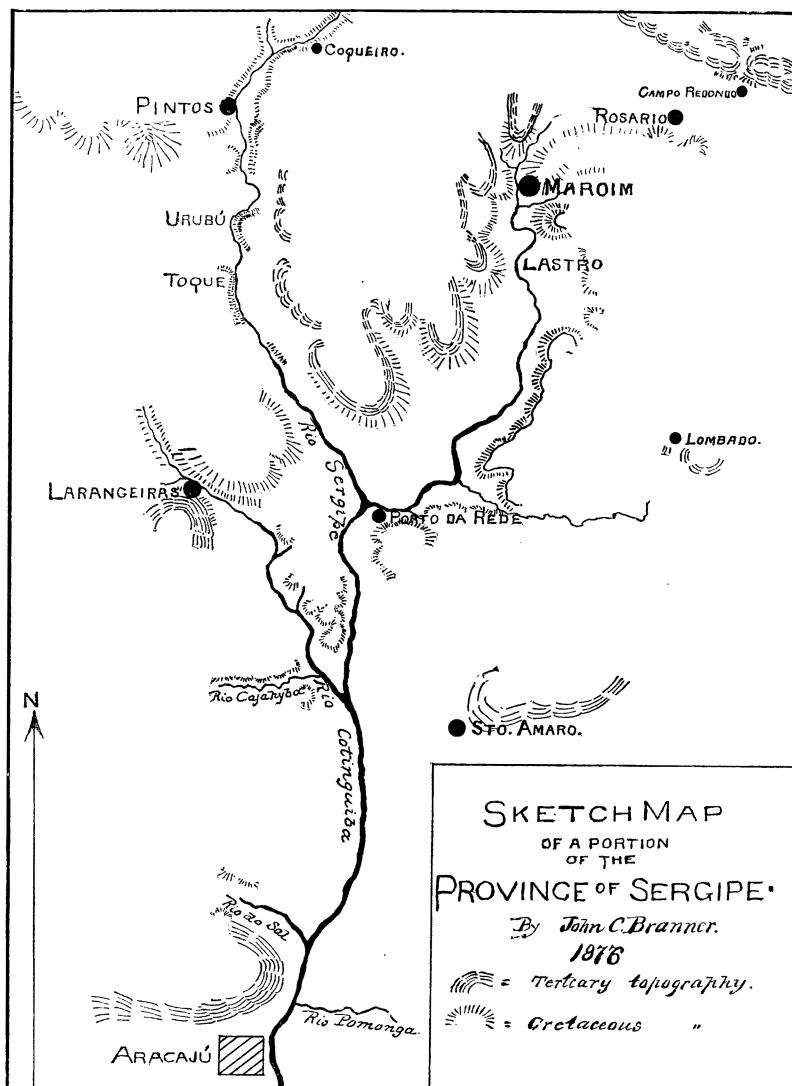
Most of the material collected at Coqueiro came from a single locality, a small exposure in the *estrada real* within a few hundred yards of the engenho of this name. The rocks here are sandstones of very uneven texture, being in some places hard, in others soft, in some places fine grained, in others coarse and porous, while in others still they contain a great many quartz and other pebbles. Among these pebbles are some of black quartzite resembling very strongly the dark quartzites found in situ in the serra d'Itabaiána. Owing to local variations in the character of these sandstones, some portions of the beds contain no fossils, all of them, if any ever existed in such places, having been removed by percolating waters. The most abundant fossils are conchifers, *Trigonia subcrenulata* being especially plentiful, and these occur for the most part as moulds or casts, the shells having been entirely dissolved out. In some of the finer-grained portions of the beds many impressions of small and delicate lamellibranchs are found, but the rock is so friable that they can be extracted only with great difficulty. The scarcity of gasteropods in these beds is somewhat striking.

To the north of the engenho is a small quarry in which the rocks are very hard yellowish sandstones, from which the fossils cannot be successfully removed. East of the river (Sergipe), at a place called Pocinhos, about seventy-five feet of sandstone is exposed. This exposure also shows a wide range of material in its composi-

tion, being in places very fine, in others containing a few pebbles, while in others it is a decided pudding stone containing cobbles half the size of one's head. Fossils are very scarce here, only a few bivalves being found in the lowest beds. The fact that the collections made here afford several fossils of jurassic aspect renders the locality one of special interest.

The beds are identical with those exposed at Porto dos Barcas, Trapiche Maior, Trapiche das Pedras Velho and Trapiche das Pedras Novo, though they vary considerably between these various localities in lithologic characters.

#### EXPOSURES ALONG THE RIO SERGIPE.



Many of the paving blocks and stone steps used in the village of Riachuello (also called Pintos) are filled with small gasteropod shells and other fossils, and a

small collection of the fossils of the neighborhood was made at one time by Dr. Dionizio Eleuterio de Meneses, the proprietor of Engenho Moleque near the village. At this engenho is an exposure of soft sandstone, but the fossils in it are not well preserved or readily extracted. The rocks in the vicinity of Riachuello were not examined thoroughly, and no doubt more interesting localities than any found remain to be explored here. Between the village and the engenho Jesus Maria José are several localities which yield good fossils. At the last-named place an exposure in the public road furnishes an abundance of them. Another locality is the Engenho São José de Vieira, and between it and São Felix are the largest and best preserved gasteropods found anywhere in the Sergipe-Alagôas basin, many of them lying weathered in the fields. A few of these were collected, but they seem to have been lost, for they were not included in the collection sent Dr. White with the other mesozoic material from Brazil to be described. At São Felix is the only exposure between the São José de Vieira locality and Riachuello.

At Trapiche Santa Maria in the outskirts of this village and on the river bank, a soft, non-fossiliferous sandstone is exposed, having a low dip to the north  $15^{\circ}$  east. This rock, in general appearance, very strongly resembles that exposed at Araçá and Pamonha. At Trapiche das Pedras many large gasteropods were found in a calcareous sandstone on the east side of the river.

About two hundred yards up the river from Trapiche Maior is a ledge of soft sandstone exposed at the margin of the stream near a tile factory, and containing many fossils, and especially bivalves. At Porto dos Barcos an exposure at the margin of the river, and which is uncovered at low tide, dips N.  $20^{\circ}$  E. The rocks at all the above localities dip beneath the oolitic limestones of the Urubú and Imbira bluffs.

I find in my field notes, written upon the spot, a statement to this effect: That "the Coqueiro beds are the same as those of Trapiche Maior, Porto dos Barcos, and Trapiche das Pedras." The importance of these facts will be made apparent in the discussion of the jurassic aspect of some of these beds. My notes upon the detailed geology of these localities (Porto dos Barcos, Trapiche das Pedras, and Trapiche Maior) are meagre, the collecting at these places having been done principally by Dr. Freitas.

#### *Urubú and Imbira.*

The locality known as Urubú is a bold cliff of oolitic limestone of grayish and greenish gray color, from one hundred to two hundred feet high, having a N.-S. trend, and dipping approximately  $37^{\circ}$ , S.  $70^{\circ}$  E. Along the weathered face of this

bluff many well-preserved specimens of *Echinobrissus freitasii*, White, were found. Below this point another and similar exposure of cream-colored to gray oolitic rocks, about seventy-five feet high, is known as Imbira. The rocks here dip about 30°, S. 70° E. These oolitic limestones are weathered along the joints, and contain many large caverns from whose roofs stalactites descend to their floors.

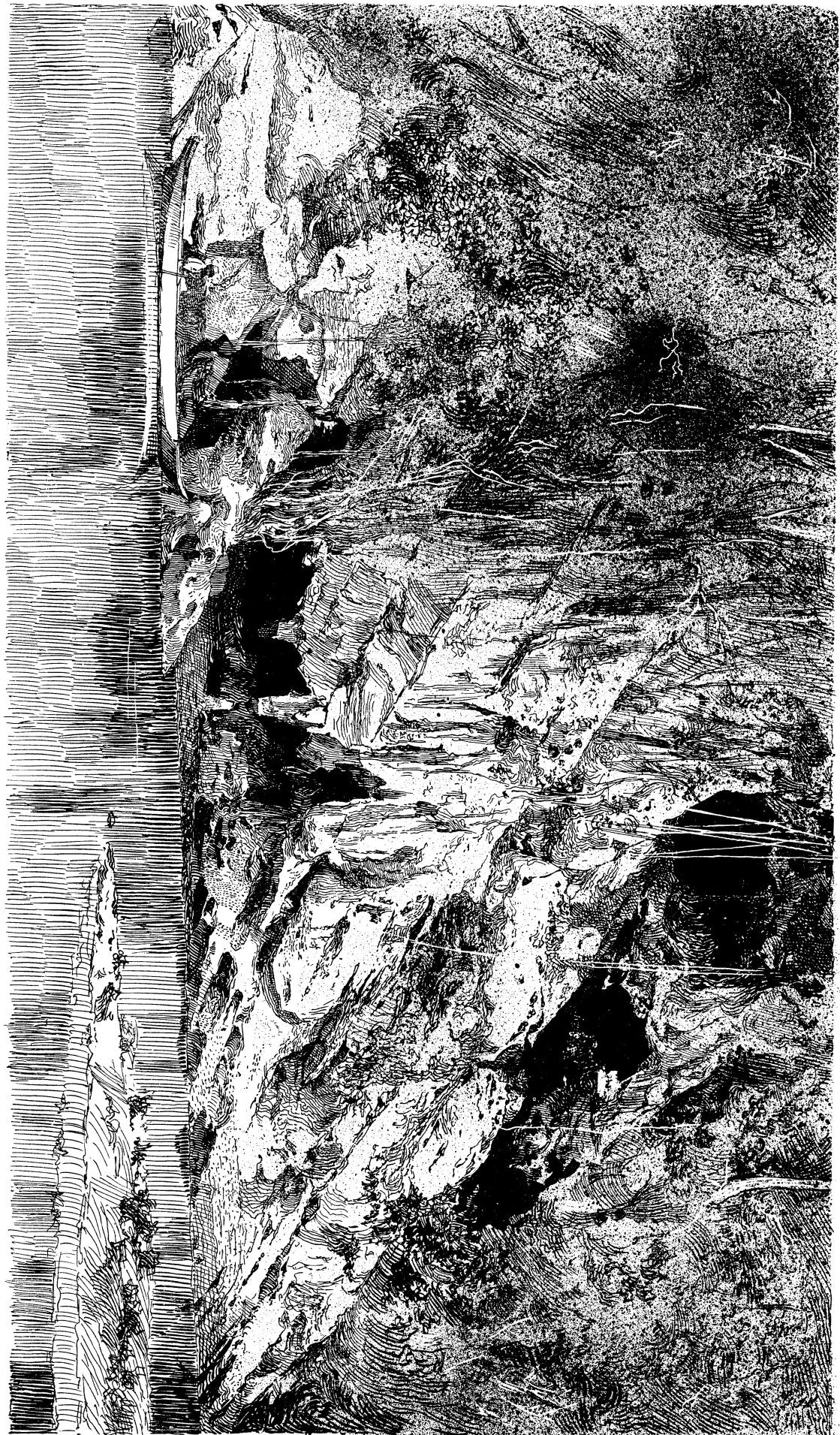
At Canna Brava white to gray oolitic rocks dip S. 45° W. at a low angle. Below Canna Brava, at a locality on the west side of the river, known as Toque, are good exposures of limestone. These rocks are somewhat metamorphosed in places, and only one bed yields many fossils. The rock is firm and compact, and weathers in jagged, irregular masses which, when struck with the hammer, ring like "clink-stones," from which peculiarity the place doubtless takes the name "Toque." In a few places caverns are developed in it. The beds here dip about 20°, S. 65° E.

About a thousand feet below Toque similar beds are exposed at Capoeira on both sides of the river. On the west side these form a bluff about one hundred feet high. Being very compact and partially metamorphosed, they furnish but few fossils, and these come from a single stratum and bear a strong resemblance to those found at the Lastro locality near Maroim. The exposures on the left bank of the river dip 13°, N. 70° W., while upon the right bank the dip appears to be S. 70° E., angle not determined. Rocks similar to these are exposed again further down the river at several places, the most important one being known as the Pedra Branca. Here they are exceedingly compact and partially metamorphosed, in places resembling marble, while the fossils have been almost entirely obliterated, the ones found having a general resemblance to those of the Lastro locality. The exposed upper surfaces of the rocks weather in sharp, jagged points.

Half a mile from this point on the river, at the margin of the mangue, are found fragments of a bed of limestone cropping out at the base of the hills, which fragments contain a great many flint nodules.

The only other exposure of importance on this stream, that is, on the Rio Sergipe proper, and below the last-mentioned place, is at the limestone quarries of Andorinhas. At several places soft, cream-colored flagstones are quarried both for paving stones and for making lime. In general appearance these limestones resemble those quarried at Sapucary, though they are not quite so pure or so fine grained. These rocks contain occasional imperfect impressions of large cephalopods and the remains of decapod crustaceans. The dip here is generally toward the east, though the rocks have some appearance of being flexed.

The next exposures down stream are those of the Sapucary quarries on the west



The Caverns of Urubu, Rio Sergipe.

side.\* The rock here is a soft, cream-colored limestone, in laminæ from one to five inches thick, and coming out as flagstones. These flags are extensively used for paving-stones in Aracajú. They dip to the east at an angle varying from  $25^{\circ}$  to  $40^{\circ}$ . But few fossils have been found in these rocks, and these have been the scales of fishes. The locality is described also by Prof. Hartt in his "Geology and Physical Geography of Brazil," p. 383.

These Sapucary beds appear to be the highest of cretaceous age exposed in this region, the next exposures to the east being coarse, ferruginous sandstones, which, in all probability, belong to the tertiary. If, from Sapucary, one ascends the stream toward Maroim, many cretaceous exposures may be found in the vicinity of Porto da Rede. The rocks to the east of this village are limestones, both hard and soft, many of them containing black flint nodules. They are exposed in many places near the water's edge, along and in the margin of the mangues. The dip is approximately to the east at an angle varying from  $25^{\circ}$  to  $35^{\circ}$ . None of them form prominent features in the topography of the neighborhood.

#### EXPOSURES ABOUT LARANGEIRAS.

The most interesting place in the vicinity of Larangeiras is just outside the town, along the road leading to Maroim. Here hundreds of large cephalopods (mostly *Ammonites (Buchiceras) harttii*, Hyatt) and echinoderms (*Echinobrissus freitasii*, White) lie weathered out in the road. Some of these fossils are badly bruised by the wear of travel and their being knocked against one another, while others, more recently weathered out, are fairly well preserved. The material from this locality, and belonging to the Comissão Geologica was labeled "Bom Jesus" after the name of the engenho to which the lands belong, and this is the locality referred to in Dr. White's descriptions. From this point toward Maroim, at the Engenho Pedra Branca, is a quarry of impure limestone dipping south-west.

A half a mile west of Larangeiras is a place known as the Pedra Furada, or pierced rock. A bed of limestone about twenty feet thick is here exposed in an isolated bluff made prominent by lateral weathering. Lithologically this rock strongly resembles that found at Capoeira and Toque on Rio Sergipe, and of which bed it seems to be the southward extension. The strata dip about S.  $45^{\circ}$  E. at a low angle.

\* Prof. Hartt gives the name of this place as Sapucahy, and in the notes sent Dr. White by Mr. Derby on the geology of the province of Sergipe the name is so given. Sapucahy being the name of a Brazilian tree, it is quite natural that this mistake should have occurred, and that it should be held as an intelligible word. In spite of this the people at and about the place called it Sapucary, and this, of course, determines its name.

In the town of Larangeiras is a quarry on the east side of the stream, the rocks having a general resemblance, both in lithologic appearance and in fossils, to the harder portions of the Lastro and Jaque exposures near Maroim.

Several outcrops of cretaceous rocks occur along the Cotinguiba, the stream upon which Larangeiras is situated. Above the mouth of the Rio Cajahyba which flows into the Jacaresíca from the west, there is a quarry of white limestone at the Caes da Ilha on the east bank of the river. A section of about twenty feet of this rock is exposed here. At Oiteiro Galante, on the east side, the same rock shows again in a less prominent exposure. Neither of these places was carefully examined by the writer.

#### ESTANCIA.

At Estancia the most prominent rock exposures are the red sandstone down which runs the cataract of the Rio Piauhy at this place. In general appearance these beds resemble, in a very striking manner, the triassic red sandstones of New Jersey, United States, and also those at Penedo on the Rio São Francisco. No fossils have been found in them.

Between the city and the port on the river the rocks exposed are dark-brown sandstones varying to conglomerates containing pebbles of gneiss and clay ironstone concretions of various sizes up to six inches in diameter. These rocks have a dip of from two to five degrees to the north-west. I am inclined to think, however, that this is an exposure of tertiary instead of the harder sandstones so well shown in the river.

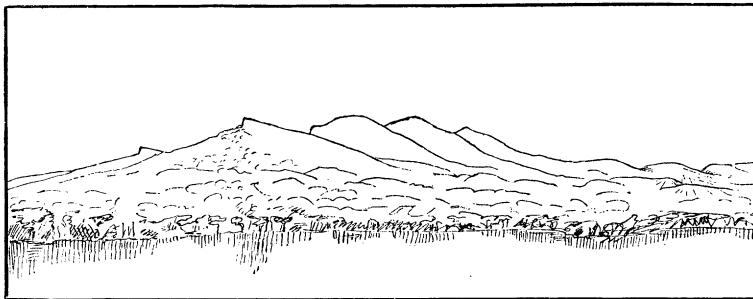
At Ribeira Velha are exposures of the tertiary. The locality of especial interest in this neighborhood is a place known as São Gonçalo, where a few cretaceous fossils were found. The exposure, however, is a very insignificant and unsatisfactory one, where the soft limestones have been dug out for making lime. In this exposure the beds are gently arched, the most prominent dip being to the north-west (?). The uppermost bed is a coarse white sandstone, next below comes a band of fine, soft limestone, then gray limestone of a chalky appearance, and at the base a bed of plastic blue clay. The quarrymen spoke of having found *panellas* (frying-pans) in the rocks, which, from additional descriptions, were supposed to be large cephalopods. No examples, however, were seen.

#### THE MARÁBA SERIES.\*

That the Marába beds bear the same relation to the mesozoic rocks in the province of Alagôas as do those of Itabaiána to the mesozoic rocks in Sergipe, there can

\* The Serra de Marába is said to be the highest point in the province of Alagôas.

scarcely be a doubt. Looking north-east from the Rio São Francisco, a short distance below Propriá one sees the Marába as shown in the following cut; the inland



Serra de Marába from near Propriá, Rio São Francisco.

or north-west side of the hills presenting abrupt faces, the south-east slope having a gentle dip toward the sea, suggesting that, if composed of sedimentary rocks, they must dip beneath the horizontal tertiary beds which cover the greater part of the region in the immediate vicinity of the mountain.

An examination of the country between Penedo and the serra shows that this impression is the correct one. Leaving out of account the sandstones underlying the city of Penedo, in going from this place to Marába, one traverses a wide belt of low, flat, fertile country which borders the river, and which is more or less flooded by the *enchentes* or "freshets" of the Rio São Francisco. From this low country he rises gradually and almost imperceptibly upon the taboleiros or plateaux, which are composed of the horizontally bedded clays and sandstones of the tertiary. These beds continue high up the south-east face of the Serra de Marába and end uncon-



Section through the Serra de Marába.

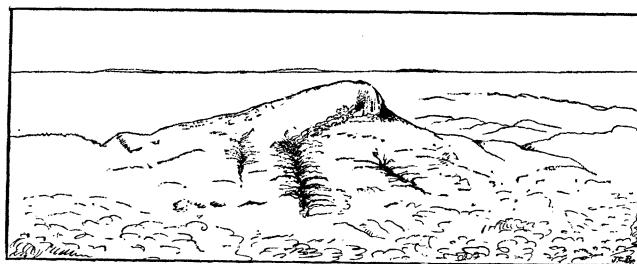
formably against it. They (the tertiary beds) are cut through by the ordinary processes of subaerial erosion, and, if careful search could be made, it is probable that exposures of the cretaceous, or at least of rocks higher than those seen on the summit and face of Marába and lower than the tertiary could be found. At Igreja Nova, a hamlet near the south-east base of the mountain, several loose fragments of compact limestone were found strongly resembling that which occurs near the top of the Itabaiána series, but the rock was not seen in place.

The serra itself, as seen in the few exposures on the top, is composed of light-colored sandstones dipping at an angle of about  $40^{\circ}$  to the S. E.\* These rocks are much jointed, and in many places changed to quartzites. The contact between the paleozoic and

\* The slope of the hill where it was seen to correspond with that of the rocks is here given as the dip. The rocks are so metamorphosed that it is difficult or impossible, to obtain the dip directly.

archæan at the base of this serra was not seen, being covered by soil and the talus from the abrupt northern face of the ridges. Not far north of this escarpment the gneisses, such as are seen at the base of Itabaiána, crop out.

From the summit of the Marába and bearing S.  $25^{\circ}$  W. is another peak of this same range known as the Urubú, shown in the following cut, having the abrupt north-



Pico do Urubú from Marába.

west face and the south-east dip characteristic of the Marába. From Marába, Propriá on the Rio São Francisco is visible in the distance, and to the left of that place, though far beyond the river, appears a broad plateau with its higher face to the inland side and sloping gradually oceanward, but dying out in the flat country long before the ocean is reached. This plateau was judged at the time and on the ground to be the continuation of the cretaceous beds of Sergipe in the Alagôas direction.



Fig. F. Pico da Serra Grande from Marába.

Bearing N.  $70^{\circ}$  E. the Pico da Serra Grande (Fig. F) is the next prominent peak in this range, its beds also apparently dipping south-east beneath the tertiary. Farther away a line of peaks form the north-easterly continuation of this range.

#### LITHOLOGIC CHARACTERS.

No exposures have ever been found of these Sergipe-Alagôas cretaceous rocks sufficiently continuous to make it possible to determine with any degree of satisfaction whether their lithological characters are constant or otherwise, when long distances or wide areas are taken into consideration.

Without going into tedious details I may say, however, that all the evidence in my

possession points in one direction, namely, that the lithologic characters are not only not constant in these beds, but that they often change very radically within a thousand or two thousand feet.

The oolitic beds, so prominent a feature of the Maroim region, do not appear as such on the Rio São Francisco, where the entire Sergipe-Alagôas series is cut through by the river. The red sandstones of Penedo do not appear as such about Maroim, while they are a conspicuous feature of the geology in the region about Estancia. The shales of Maceio are not seen elsewhere in the basin at any considerable distance from Maceio, and the arenaceous beds of Villa Nova are not known to exist in any other part of the basin.

The rocks vary in texture and character between the following kinds:

1. Coarse, compact sandstone of a bluish-gray color, modified by weathering to brown, and light gray; fossils preserved but difficult of extraction. Example, Riacho de Aroeira.

2. Coarse to fine friable sandstone of open or porous structure; fossils preserved mostly as molds or casts. Example, Coqueiro.

3. Oolitic limestone, bluish and greenish, weathering to light gray, cream-colored and brown. Examples, Urubú, Maroim, at the Gambarobe and Lastro quarries. The brown and cream colors of the oolitic beds are apparently products of incipient decomposition, the bluish and green tints predominating where these rocks are quarried to considerable depths, the brown and cream colors appearing near the surface and where the rocks are penetrated by joints or otherwise made accessible to meteorologic agencies.\*

4. Cream-colored, lead-colored and white, soft limestone. Examples, the quarries of Sapucary and Andorinhas.

5. Limestone, more or less compact, without well-preserved fossils, and with flint nodules. Example, Toque below Canna Brava.

\*The following is a brief description of thin sections of specimens of these oolitic limestones examined under the microscope:

The body of the rock is made up of irregularly rounded patches of calcite, many of which have the characteristic oolitic structure. There are, besides occasional grains of quartz, a few fragments of greenish mica, and here and there patches of brown hydroxide of iron. All these constituents are cemented together with fine, almost colorless, granular calcite. The oolites are stained a dull brown or cream color, and stand out prominently in the cement. There is nothing unusual in the oolites themselves. They are made up of concentric rings of calcite grains one outside the other, the innermost one usually enveloping a small fragment of organic matter, such as a bit of shell.

Many examples occur among these oolites, however, in which the general mass is not made up entirely of these concentric rings, the formation of these having ceased at a certain point, while beyond this the calcite has been added principally upon one side of the already formed mass, and without any definite arrangement. In some cases two partly-formed oolites are cemented by this amorphous calcite, the united mass retaining the usual irregularly-rounded form. In other cases still later formed concentric bands have enveloped the oolites thus united.

## THE AGE AND CORRELATION OF THE MESOZOIC BRAZILIAN ROCKS.

Although the mesozoic beds of the region under discussion are here spoken of as cretaceous, the writer is aware of certain conflicting evidence in regard to their age, which should not be overlooked.

Prior to the study of the cretaceous fossils of Brazil by Dr. White, the age assigned to the beds from which these fossils were derived was more or less unsatisfactory.

Although undoubted paleozoic deposits occur in many places in Brazil, no fossiliferous strata have as yet been discovered immediately beneath the cretaceous, while the overlying beds, referred to the tertiary, have never yielded any fossils, and have been so referred solely on account of their relation to the strata underlying them. It is plain, therefore, that the determination of the age of these rocks must be based entirely upon internal evidence, a determination which, on account of the incompleteness of the collections or the want of study, has always been more or less unsatisfactory up to the publication in 1888 of Dr. White's important "Contributions to the Paleontology of Brazil."

Prof. Hartt, in his "Geology and Physical Geography of Brazil," p. 385, says that when, in 1869, the cephalopods collected by him at Maroim were shown to Prof. Alpheus Hyatt, he was at once struck by their jurassic aspect, although in the description of these fossils, which is published at length in Prof. Hartt's book (*op. cit.*, pp. 385-393), nothing is said upon this subject, while they are all said to have come from "the cretaceous beds of Maroim."

Prof. Hartt says (*op. cit.*, p. 393) that the limestone about Maroim is undoubtedly upper cretaceous, though he does not tell us upon what evidence this opinion is based.

The Brazilian cephalopods described by Prof. Alpheus Hyatt in Hartt's "Geology" had been collected by Prof. Hartt from what he considered undoubted cretaceous rocks. Some of these fossils, however, were of decided jurassic affinities, and both their stratigraphic position and peculiar state of preservation warranted Prof. Hyatt in endeavoring to account for their occurrence at such a horizon. Prof. Hartt felt confident that the Sergipe rocks were cretaceous; the fossils were evidently much worn, and had a decided jurassic aspect. Prof. Hyatt therefore suggests\* that these cephalopods may have been eroded from beds at a lower geologic horizon (the jurassic) and transported to and deposited in the cretaceous. The suggestion is a natural one for a person unacquainted with the peculiar circumstances under which these fossils occur, but it is only necessary to say here that a knowledge of these circumstances does away with the necessity of this supposition. The fossils were taken from their original beds, and there is no reason for

\* Proc. Boston Soc. Nat. Hist., Vol. XVII, p. 370.

supposing that they have been redeposited, as I shall show hereafter, and the case is mentioned in this place only to call attention to what is either conflicting testimony regarding the age of the Sergipe rocks, or to a mingling in them of jurassic and cretaceous faunas.

M. Emmanuel Liais, in speaking of the secondary deposits of Brazil, in his "Géologie du Brésil" (p. 197) says: "Ce puissant dépôt secondaire, tout paraît l'indiquer d'ailleurs, a dû se former pendant au moins une grande partie de l'époque crétacée, et a peut-être commencé dès l'époque jurassique, au moins dès la période oolithique. Peu de perturbations auront eu lieu dans ces immenses régions pendant cette longue durée, et par là s'explique comment les espèces du commencement de la période ont pu continuer d'exister et se mêler aux espèces postérieures, de sorte que, suivant la très judicieuse remarque de Darwin, confirmée, comme nous l'avons vu, par l'union d'espèces jurassiques et crétacées dans les divers dépôts du Brésil, les deux époques ne sont pas nettement séparées comme en Europe."

No direct reference, however, is here made to the mesozoic geology of the Sergipe-Alagôas basin. The writer has not been able to locate this opinion of Mr. Darwin, and does not know upon what evidence it is based, but from the limits of his (Darwin's) observations in Northeastern Brazil, it is presumed that such an opinion by Mr. Darwin must necessarily have been based upon evidence accumulated by him in the Argentine Republic and Patagonia.

In his "Contributions" Dr. White gives the following reasons for calling the rocks of the Sergipe-Alagôas region cretaceous (p. 15): "First, the majority of the types are such as are generally regarded as characteristic of that period. Second, a portion of the species are identified with published species of undisputed cretaceous fossils in other parts of the world. Third, although some of the species have a jurassic aspect, none of them are identifiable with any known jurassic species. Finally, as all the collections have been shown to belong to one fauna, and a part of its species to be certainly of cretaceous age, the whole fauna must necessarily be referred to that period." This decision is somewhat weakened, however, by a statement (on p. 6) to the effect that "while such a conclusion would, I think, have been reasonably reached from a study of the fossils alone, much reliance has been placed in the corroborative testimony of the geologists of the Brazilian Survey."

If the members of the former Brazilian survey were now asked to give their reasons for calling these rocks cretaceous, they would lay all stress upon Dr. White's determinations and none at all, or very little, upon any evidence that has been adduced from stratigraphic relations, simply because, as has already been said, those

relations have, as yet, thrown but little or no light whatever upon the age of these particular beds.

In the mind of one acquainted with the mesozoic geology of Brazil, this fact stands forth prominently: that while Dr. White's conclusion that these beds are cretaceous, must be accepted, the fauna presents peculiarities of its own in the jurassic facies of the Sergipe-Alagôas fossils. Another peculiarity of this cretaceous fauna of Brazil is that certain of the typical genera, as Dr. White says, if found alone, would be referred to the tertiary. It may be due to the incompleteness of the collections made, but as far as we know these tertiary forms, *Fusus*, *Murex* and *Phorus*,\* occur only in the Pernambuco and Pará collections, and not a single example is reported from the Sergipe-Alagôas basin; while, on the other hand, not one of the jurassic forms is reported from the Pernambuco or Pará beds.

Thus far the writer has spoken of the mesozoic beds of this region as a whole. Let us now ascertain, if possible, whether or not both jurassic and cretaceous beds exist here, and whether this apparent mingling of faunas may not be due to bad collecting.

#### *The Stratigraphic Relations of the Mesozoic Beds.*

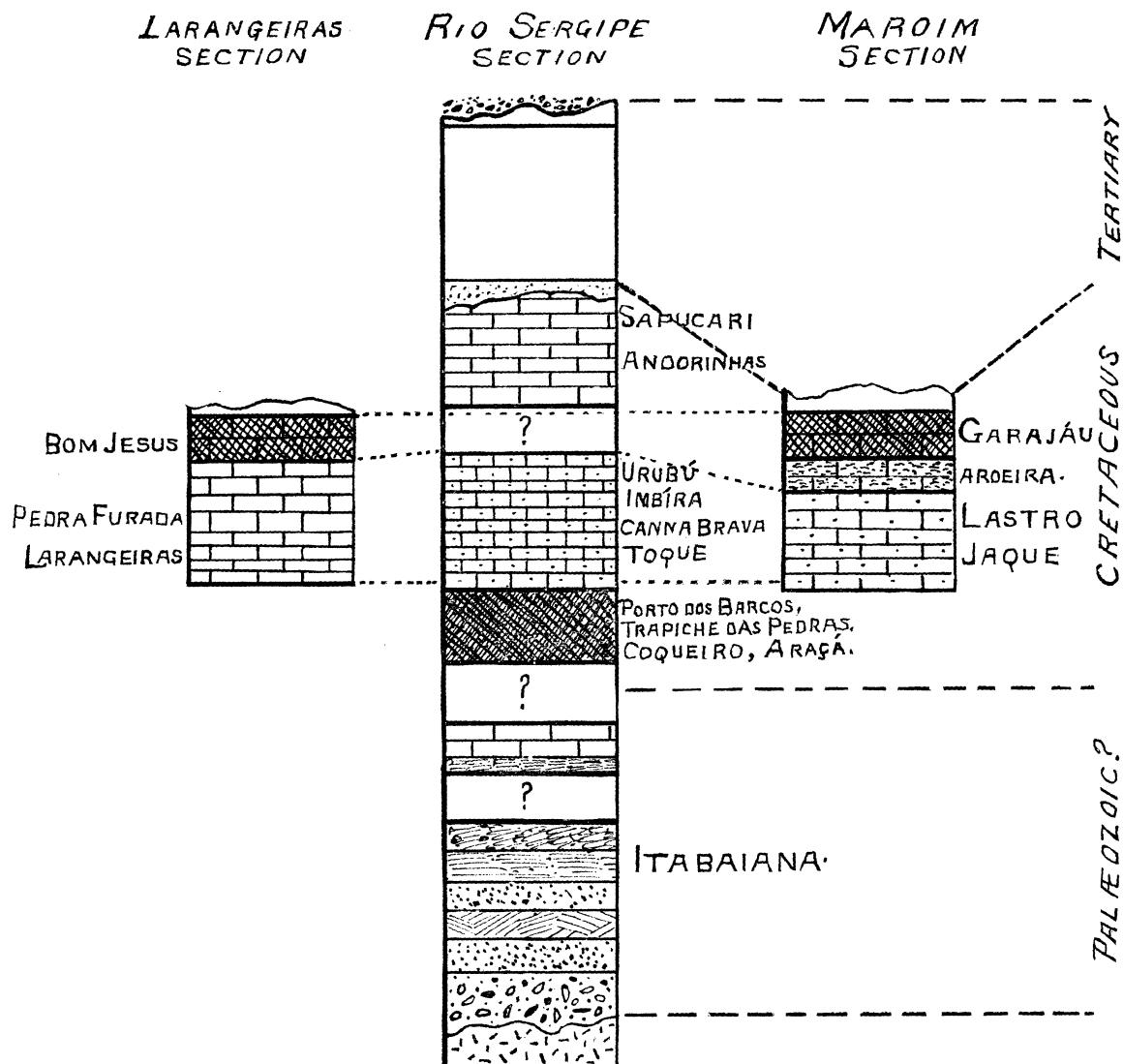
The general relations of the rocks of the separate groups are shown in the section through Itabaiána, and it only remains to indicate the relations of the mesozoic beds to each other. The details of these relations throughout have not been determined with any degree of satisfaction, the time spent in the province having been taken up entirely either in hasty reconnaissance or in collecting fossils. In the few more important instances in which these relations are known they are shown in the accompanying illustrations. In view of the very interesting departure of the fauna of this group from what would be regarded as a typical cretaceous fauna, the lack of detailed information upon this subject is the more to be regretted.

In Prof. Hyatt's paper upon the cephalopods of this region, no definite locality is mentioned for these fossils than "the cretaceous beds at Maroim." I learned from Prof. Hartt subsequently that this collection was taken, almost entirely, from the paving stones in the streets of Maroim. Now the quarries from which these paving stones came are so numerous and at such different horizons, that these fossils cannot be located stratigraphically, and for this reason, no valuable paleontological deductions can be made from them in determining the faunal characteristics and relations of the separate beds in the vicinity of Maroim.

\* This statement is made solely upon the authority of Dr. White's opinion as expressed in his "Contributions to the Paleontology of Brazil," p. 17. But inasmuch as *Fusus*, *Murex* and *Xenophora* (*Phorus*) begin in the cretaceous or earlier, it seems to be of doubtful value.

One of these cephalopods, however, *Ammonites (Buchiceras) harttii*, Hyatt, as it appeared afterwards, came from the locality known as Bom Jesus. The jurassic aspect of this fossil and the eroded condition of the specimens led Prof. Hyatt to suggest the possibility of its having been transported from some older deposit.

The section given herewith shows the relation of the Bom Jesus beds to others of this group.



Three sections in the Sergipe-Alagôas basin. (The heavily shaded beds yield fossils of jurassic aspect.)

The Bom Jesus beds occur in the hilltops east of the town of Larangeiras. The rocks are earthy, arenaceous limestones which are readily attacked by disintegrating agencies, and have, therefore, been rapidly converted into residuary earths. The

fossils occur, for the most part, lying loose in the road where they have constantly been ridden and walked over, or are imbedded in the black residuary earth that covers these cretaceous hills. In many cases, however, there are irregular blocks of the matrix preserved along with the fossils. The worn appearance of a great many of the specimens from this locality is due to two causes: one is the rapid dissolving action of the rain-water, which when raised to a high temperature by falling upon the hot rocks, attacks them vigorously and leaves an etched surface such as is produced by acid acting upon a calcareous sandstone; the second is the wearing of the rocks against each other where they are constantly walked and ridden over in the road. There is nothing in the rocks themselves, in their topographic position, or in their relations to the underlying strata to lead one to suppose that these fossils have been carried here from a lower geologic horizon.

Attention is called to the relation of the Bom Jesus beds to those of Larangeiras and Pedra Furada, and to the fact that the Larangeiras beds are the equivalents of those of Lastro, etc., at Maroim, and of those of Urubú on the Rio Sergipe.

At Maroim the Lastro beds are overlain by a similar cephalopod-bearing formation, that of Garajáu, which yields other fossils of jurassic aspect, while those of Urubú, the equivalents of the Lastro beds, overlie others of decidedly jurassic facies.

We have then the following arrangement of the strata:

1. At the top are the Garajáu and Bom Jesus beds, yielding fossils of both cretaceous and jurassic aspect.
2. Beneath these are the Lastro, Jaque, Urubú, Imbira, Toque, Capoeira, Larangeiras, and Pedra Furada beds, whose fossils are all referable to the cretaceous.
3. Beneath these are the beds of Porto dos Barcos, Trapiche Maior, Trapiche das Pedras Novo, Trapiche das Pedras Velho, and Coqueiro, all of which yield fossils of both cretaceous and jurassic aspects.

As the jurassic aspect of both the underlying and the overlying beds might tend to throw doubt upon the reference of those of Urubú, Lastro, etc., to the cretaceous, I can only refer to Dr. White's able discussion of this subject in his "Contributions" (pp. 15-16), where he shows that the weight of evidence favors the cretaceous age, not only of those particular beds, but of the entire Sergipe-Alagôas series.

It is no longer cause for surprise that beds of decided jurassic aspects are found overlying others of just as marked cretaceous aspect. Dr. Blanford, in his presidential address before the Geological Section of the British Association at Montreal in 1885, laid timely stress upon these apparently anomalous conditions existing in India and South Africa, and to the grave difficulty or impossibility of an exact and minute

correlation of the beds deposited in such widely separated regions as Europe, South Africa, India, Australia and South America.

It is worthy of note also in connection with the discussion of the mesozoic and tertiary rocks of Brazil that the fossils of jurassic aspect are confined to the Sergipe-Alagôas basin and to the Crato district in Ceará,\* while those which have a tertiary aspect are, so far as they have been worked out, entirely from the Pernambuco and Piábas basins.†

Inasmuch as the divergencies between the faunas of the Sergipe-Alagôas basin and the Pernambuco basin tend to associate the former with the older and the latter with the newer geological horizons, the probability is naturally suggested that the Sergipe-Alagôas beds are more nearly synchronous with those of Crato in Ceará which are referred by Newberry and Cope to the jurassic, while the Pernambuco beds are similarly related to those of Piábas in the province of Pará.

#### THE CONDITIONS ATTENDING THE DEPOSITION OF THE MESOZOIC BEDS.

The rocks represented in the sedimentary beds of the Sergipe-Alagôas sections vary from the coarse conglomerates at the base of Itabaiána and lying in contact with the gneiss, through sandstones, quartzites, shales, slates and dolomitic limestones all of possible paleozoic age. In the mesozoic beds the rocks are sandstones, coarse, fine, and often calcareous. These are variously colored from dark red through brown to cream colored. The limestones are arenaceous, partially crystalline with flint nodules, oolitic and cherty.

The nature of these mesozoic beds indicates that the changes which took place during their deposition were not very great or very sudden. The sandstones lie at or near the base of this series, the oolitic beds follow, and the soft limestones are the highest ones seen.

The order and character of these beds appear to indicate a gradual subsidence of the region from the beginning to the end of the cretaceous. The basal sandstones often contain pebbles the size of a partridge egg, and sometimes the fossils are rolled and water-worn, showing that they were deposited in tolerably strong currents and near the shore. The earthy limestones and oolitic beds which follow indicate an increasing depth and quieter waters, while the uppermost beds have been deposited

\* See opinions of Dr. J. S. Newberry and Prof. E. D. Cope concerning the fossil fishes of Ceará in Proceedings of the American Philosophical Society, Vol. XXIII, Jan., 1886.

† See Dr. C. A. White's "Contributions to the Paleontology of Brazil," p. 17, and Prof. E. D. Cope in the Proceedings of the American Philosophical Society, 1886. In the latter paper Prof. Cope compares the Pernambuco vertebrate fossils with those of the Fox Hills (upper cretaceous) of the United States.

in still deeper and quieter water than any of the lower ones, are more homogeneous, and contain the remains of fishes and a few cephalopods. No shallow water animal's remains have thus far been found in them. Then followed the pressure that folded broke, and in places, partially metamorphosed, the cretaceous beds. This ended the depression of the ocean's bottom.

*Pressure.*—The cretaceous beds of the Sergipe-Alagôas basin have been subjected to more or less pressure, though this pressure has not been uniform.

The following are the evidences of such pressure:

1. Many of the fossils collected in this region are more or less crushed or otherwise distorted.

2. The beds as seen near Maroim, at the Lastro, and at other places along the Maroim arm of the Rio Sergipe, and especially along its western bank, are thrown into folds.

3. Slaty cleavage is noticeable in the Ilha do Chaves, a mile below Propriá.

4. Superinduced cleavage and joint structure are seen in the sandstones of the Serra d'Itabaiána and in those of the Serra de Marába.\*

In some localities the limestones are metamorphosed, and their fossils completely obliterated, while in many other places the obliteration of the fossils is but partial.

The folds in these rocks indicate that the pressure by which the region was disturbed came from the south-east. Although this pressure was sufficient to flex the cretaceous beds, and, in places, to metamorphose them more or less, there is nothing to show that it was great. The flexures are usually gentle and the rocks seldom dip at a high angle, as will be seen from the accompanying table of dips.

#### ECONOMIC.

It is not to be wondered at that the popular notion that precious metals must occur in all mountainous regions, has led to the supposition that the serras of Itabaiána and Marába are auriferous. These mountains have been examined repeatedly in the search for gold, silver and what not, but without success. As long ago as the seventeenth century they were explored and found barren of such riches.† At the

\* Certain other sandstones of this region are partially metamorphosed. In some places this metamorphism is complete, while in others it is but slight. There seems to be some doubt as to the exact place of these metamorphosed sandstone beds in the series, but the weight of testimony seems to show that they are tertiary. The metamorphism of these particular beds cannot, I think, be adduced in support of the theory of pressure, for it is entirely due to weathering.

† "Within the jurisdiction of this captainship ('Sergipe del Rey') is the mountain of Tabayana; from whence several valuable ores were presented to the council of 19; but, upon proof, were found not worth farther looking after." 1641. Voyages and Travels into Brazil by John Nieuhoff. Pinkerton's Voyages, Vol. XIV, p. 706.

time when the gold and diamond diggings of Brazil were at the height of their successful operation, extensive explorations were carried on in these mountains. Even during the last twenty years such explorations have not entirely ceased, though they have never given any promise of success.

There is nothing in the geologic structure, as far as it is known, to lead one to expect deposits of economic value in the mountains of Sergipe and Alagôas.

It is possible that from the soft chalky beds at Andorinhas and Sapucary commercial chalk could be manufactured, though I have nothing beyond the general appearance of the rock to lead me to this supposition. It may be worth testing for this purpose. The tertiary beds would yield mineral paints of various red, yellow and brown colors, but owing to the absence of demand for such paints in Brazil, they would have no value at present.

The last member of the tertiary beds, the conglomerate which is scattered far and wide over the region, yields some limonite iron ore, but this ore has not been found in any considerable quantity as yet, and in view of the vast deposits of excellent iron ores in São Paulo and Minas Geraes, it is scarcely possible that a limonite ore could be profitably handled in this part of the Empire.

There were the usual reports through the province, at the time of my stay, of the discovery of coal, silver, copper, lead, etc., but in no case did I find such reports well founded or worthy of serious attention. The coal said to have been found at Campo Redondo was the charred remains of a tree buried in the tertiary clays, while the copper discovered in the same neighborhood was a piece of the manufactured metal.

*Building Stone.*—The time will doubtless come when the beautiful oolitic limestones of the Rio Sergipe will be utilized for architectural purposes. This stone resembles the famous oolitic limestones of Indiana, so highly prized and extensively quarried and used in the United States for building purposes.

The ease with which the Sergipe rocks can be quarried and sawed and cut into blocks of any size and shape, its hardening upon exposure, its rare beauty, its pleasing tints of green, gray, brown, and cream color, its convenience to transportation by water to Aracajú and thence by sail and steamer to all parts of the Brazilian coast, may yet make it a successful rival of the beautiful crystalline rocks of Rio de Janeiro.

## PART II.

## THE BRAZILIAN MESOZOIC BASINS OTHER THAN THAT OF SERGIPE-ALAGÔAS.

In order that the relations of the Sergipe-Alagôas basin to the mesozoic geology of other portions of Brazil may be the better understood, brief descriptions are here given of all the other known mesozoic localities in Brazil. The locality in the bay of São Francisco, Province of Santa Catherina is here described for the first time.

## SÃO FRANCISCO DO SUL, PROVINCE OF STA. CATHERINA.

Of the cretaceous rocks at this place but little is known at present, and that little is due to a small collection of fossils made here in 1876, by Mr. Luther Wagoner, then topographer on the Imperial Geological Survey of Brazil. As the specimens brought away by Mr. Wagoner were collected incidentally, no observations were made by him of the extent of the deposit, and no one seems to have given the matter attention since that time. The writer visited the place in 1881, but as he was there one night only, he was unable to gain any knowledge of it. The position of the outcrop suggests that this rock may underlie the country about the bay of São Francisco. It certainly does not appear in the surrounding hilly country.

Lithologically it is a brown, earthy, calcareous sandstone resembling that found at Olinda in the province of Pernambuco. It was observed only upon a small island about six miles from the port and covered only about one acre.

The outcrop, Mr. Wagoner tells me, is very inconspicuous, near the water's edge,\* and suggests the geology of Bahia and Maria Farinha, except that the exposure is very limited. The specimens collected contained among others a number of fossil gasteropods. It should be stated here that this reference of these beds to the cretaceous is not based upon a detailed study of the fossils, but mainly upon the striking general resemblance of the fossils to those found in the cretaceous beds further north. It is to be regretted that this small collection of material was not submitted to Dr. White in connection with other mesozoic material collected by the Brazilian Survey. Of the relation of the cretaceous at this place to the older rocks nothing is known.

\* It was suggested at the time that these specimens might be fragments carried to the place as ballast, but Mr. Wagoner was confident that this could not be the case, for the rocks do not occur in fragments, but in a solid bed.

## THE ABROLHOS.

This locality is described by Prof. Hartt in the American Naturalist, Vol. II, March, 1868, and in his Geology and Physical Geography of Brazil, pp. 174-214. It was not visited by the writer, and the following facts are taken from Hartt's writings and from the series of photographs made there in 1876 by Mr. Ferez, the photographer of the Brazilian Survey. For further details reference should be made to Prof. Hartt's book.

The sedimentary rocks bear a close resemblance lithologically to those of Penedo in the Sergipe-Alagôas basin, and they seem to be referred to the cretaceous largely on account of this resemblance. They are made up of arenaceous limestone (?) beneath, blue shale above, followed by a yellowish shaly sandstone containing obscure plant impressions. These sedimentary beds are covered by igneous rock, and they all have a north-westerly dip at an angle of from ten to fifteen degrees. Neither the thickness nor the superficial distribution of these rocks is given, but both the size and the height of the islands preclude the possibility of either great thickness or extensive distribution.

## THE BAHIA BASIN.

The geology of this basin has been written upon by Pissis, Hartt, Allport, Derby, Rathbun, Marsh, Cope, and White. The description and discussion by Mr. Derby, published in the Archivos do Museu Nacional, Vol. III, pp. 135-158, written after the most thorough exploration of the region that has yet been made and with all the facts in hand that had been accumulated by previous observations, is the most nearly complete that has ever been published.

The cretaceous rocks of the Bahia basin were deposited in a fresh-water lagoon, and are therefore quite distinct from those of the cretaceous beds along other portions of the coast. The limits of the basin have never been determined except in a very general way. The following outlines are taken mainly from Mr. Derby's paper above referred to.

The eastern margin of the basin extends from the city of Bahia to the station of Catú on the Bahia and São Francisco railway, a distance of fifty-four miles. The western limits are buried beneath the tertiary hills near Cachoeira and end somewhere east of Nazareth, while the erosion of these tertiary beds gives the margin of the cretaceous exposures a ragged edge, outliers or buttes of the tertiary being scattered here and there throughout the central portion of the area. The northern margin is buried beneath the tertiary plateau which extends from near Cachoeira north of Sto. Amaro,

and crosses the Bahia and São Francisco railway at Pojúca. The south end of the basin has been cut away by the ocean, the island of Itaparica having been included in it.

Near Inhambúpe, about thirty miles north-east of Alagoinhas, Mr. Derby found disturbed beds of schists, sandstones and limestones, which he is disposed to refer to the paleozoic. It is unfortunate that he does not report the dip of these supposed paleozoic beds. While on the Rio Joannes on the east side of the basin he saw the cretaceous lying unconformably against the gneiss.

The cretaceous rocks of the basin are conglomerates, sandstones, shales and limestones. The invertebrate fossils are described by Dr. White in his Contributions to the Paleontology of Brazil.

Of these fossils Dr. White remarks, that "all the types which the fauna embraces, so far as they are determinable, are represented among mollusks now living" and that "a part of these types are at present known to exist or have existed only upon the western hemisphere."

#### THE PERNAMBUCO BEDS.

The most southerly exposure of the mesozoic beds seen in the province of Pernambuco, by the writer, was near the mouth of Rio Formozo. This exposure, however, seems to be the northern extension, and near the end, of the Sergipe-Alagôas beds, as has already been suggested. But whether it is or is not the continuation of the former, these Rio Formozo mesozoic beds do not pass to the northward of Cabo Sto. Agostinho, along the oceanward side. This cape is of quartz-porphyry,\* and on three sides is built against unconformably by particolored tertiary beds of sands and clays, a characteristic view of which is given in the part of this paper treating of the tertiary deposits.† Whether the mesozoic beds underlie the tertiary on the landward

\* Specimens of the crystalline rocks from the vicinity of Cape Sto. Agostinho, one from Estação da Ilha, collected by Professor Hartt, and two from the island of Sto. Aleixo, collected by the writer, were prepared for microscopic examination and submitted to Dr. George H. Williams, of Johns Hopkins University, Baltimore. Concerning these specimens Dr. Williams writes: "\* \* \* They must be described as quartz porphyries or rhyolites, according as they are of pre-tertiary or tertiary age. They are quartz orthoclase aggregates with almost no bisilicate constituents, but their structures are very varied. One of the specimens from Sto. Aleixo has a granular, holocrystalline groundmass of quartz and feldspar, some chlorite, possibly representing original hornblende or mica, and considerable blue tourmaline. The other Sto. Aleixo specimen is a fine granophyre. Porphyritic quartz and feldspar lie in a holocrystalline groundmass which is filled with beautiful spherulites showing the black cross between crossed nicols. The specimen from Estação da Ilha has large porphyritic sanadines with chlorite inclusions which were once glass. The groundmass is mostly composed of rectangular sanadines with much finely disseminated chlorite and iron hydroxide. Magnetite octahedrons and beautiful zircons are abundant. There is no nephelene in any of these rocks.

† See page plate of "The Ruinas de Palmyra."

side of the cape is not known, and it has been assumed that they do not, although there is nothing in the topography of the region to make such connection between the Sergipe-Alagôas beds and the Pernambuco beds impossible.

At Olinda the cretaceous rocks are exposed in the southern face of the hill upon which the church stands. The rocks are soft, earthy, somewhat calcareous, fossiliferous sandstones. This and an exposure of white limestone a short distance west of it, and known as the Forno de Cal, are the only exposures of cretaceous rocks now known in the immediate vicinity of the city of Recife, the next one to the north being in the vicinity of Rio Maria Farinha.

The region, rocks, and fossils of the Maria Farinha beds have been described by Rathbun in his paper upon the cretaceous lamellibranchs,\* and by Derby in Dr. White's contributions,† and only such of their characters as may be useful for future comparison with the other cretaceous localities of the coast need be mentioned here. Lithologically the beds vary from cream-colored and white pure limestones to earthy sandstones, all of which dip at a very low angle to the east. They are undisturbed, and none of the beds are oolitic in character. It is to be remarked that, of the several fossils of jurassic aspect in the Brazilian collection described by Dr. White, none have been found at the various Maria Farinha localities. It is also noticeable that all of the genera in this collection suggestive of the tertiary age are represented in the Maria Farinha locality, but none of them have been found at the Sergipe-Alagôas localities. These facts seem to suggest, at least, that the Pernambuco beds are not so old as those of the Sergipe-Alagôas region from which the collections were made.

It is the opinion of the writer, though it is expressed with that hesitation which should come from a lack of sufficient facts to support it properly, that the Maria Farinha and Olinda beds belong to the same horizon as those exposed three miles south-east of Penedo at Villa Nova, and that the latter overlie all the cretaceous beds from which the collections were made in the province of Sergipe.

The extent of the Pernambuco deposits has not been determined, even approximately, and it is not known, perhaps cannot be from surface exposures alone, whether the Olinda beds are, or ever were, connected with those of Maria Farinha, and whether the latter are continued by those found at Iguarassú and Goyanna, or whether those at Parahyba are also a continuation of the Pernambuco beds.

The coast between Olinda and Maria Farinha is low, and there are no rock exposures along it to aid one in connecting the two localities. From near Maria Farinha

\* Preliminary Report on the Cretaceous Lamellibranchs collected in the vicinity of Pernambuco, Brazil. By Richard Rathbun. Proc. Bost. Soc. Nat. Hist., XVII, 1874, pp. 241-256.

† Contributions to the Paleontology of Brazil. By C. A. White.

to near the mouth of the Rio Parahyba do Norte the coast is formed of a series of soft, horizontally bedded, particolored tertiary sands and clays which are readily cut and washed away by the ocean, the talus of which obscures any beds which might otherwise appear at their bases.

Cretaceous beds are exposed on the low grounds of the island of Itamaricá, while the tertiary beds form the higher lands.\* The relative positions of the cretaceous and tertiary upon this island favor the opinion that these same relations continue northward, and that the cretaceous of Parahyba is simply the northern extension of the Pernambuco beds. It is possible that a careful examination at low tides of the beds along the coast and streams from Itamaricá to Parahyba would settle this question.

No rocks referable to the paleozoic have thus far been found in the vicinity of the Pernambuco basin.

#### THE PARAHYBA EXPOSURES.

No examination of the mesozoic exposures at Parahyba do Norte was made by any member of the Comissão Geologica, and the only information that we have of them is from a few brief notes by Williamson, Agassiz, and Capanema. The rocks are soft, impure, gray limestones, dipping gently to the east, and containing but few fossils. They occur near the city of Parahyba and at Minas da Cachoeira. Their occurrence at the latter place seems to add to the probability that the Parahyba beds are simply a northerly continuation of the Pernambuco beds.† I have been unable to obtain information regarding the age of the beds immediately underlying the cretaceous rocks of Parahyba.

#### THE MESOZOIC BEDS OF CEARÁ AND PIAUHY.

Our knowledge of the cretaceous beds of the interior of the province of Ceará is derived almost exclusively from the observations and collections of Gardner made just fifty years ago. With the exception of Capanema, the many writers who refer to these beds have derived their information from him.

The facts of most importance brought out by Gardner are the geological section

\* Relatorio dos Trabalhos da Comissão Geologica do Brazil, por Ch. F. Hartt, Rio de Janeiro, 1875, p. 10.

† Among the fossils sent Dr. White from the Museu Nacional at Rio were some broken specimens of *Toxaster altiusculus* White, taken from the walls of the fort at the mouth of the river. As these specimens were collected by myself, I quote from my field notes written at the time, November the 25th, 1875 : "I found some echinoderms and shells in the walls of the old Dutch fort, at the mouth of the Rio Parahyba, but upon inquiring for the quarry from which the stone came, I was told that it was brought from Europe; at least that there are no quarries in the neighborhood yielding such stone."

of the Serra do Araripe, which, beginning at the base, consists of horizontal beds of lignite, limestone, sandstone, with chalk and flints, the sandstone stratum forming the mass of the plateau. The total thickness of the section is from 1200 to 1500 feet. The underlying rock appears to be slate, presumably paleozoic. The fossil fishes found occur in concretions scattered about the surface, which he supposed to have been water-worn. The exact position of the fossils in the section is not known. Gardner believed them to have been weathered from the sandstone bed, but Hartt, who, however, never visited the locality, expresses the opinion that they come from a bed beneath the sandstone, which he thinks, together with the overlying beds, belongs to the tertiary. The serra here spoken of trends N. N. E., and is an elevated plateau about thirty miles wide, cut down rather abruptly on both sides, the valley on the Ceará side being lower than that on the western or Piauhy side. The geographic distribution attributed to these beds by Gardner, that is, from this point to Maranhão, is not warranted either by the facts given by him, or by any that have subsequently come to light. The fossil fishes collected at and about Crato, by Gardner, were described by Agassiz, who believed them to be of cretaceous age.\* It should be mentioned in this connection, however, that Dr. J. S. Newberry and Dr. E. D. Cope regard these fishes as of jurassic age.†

#### OTHER CRETACEOUS EXPOSURES.

*Rio Mossoro, Province of Rio Grande do Norte.*—The exposure of the cretaceous on the Rio Mossoro in Rio Grande do Norte was reported by Major Coutinho. Nothing is known of the character of the beds or their geographical distribution. *V. Dr. White's Contributions*, p. 10, foot-note.

*Rio Piábas, Province of Pará.*—Concerning the Piábas locality I personally obtained from Snr. Ferreira Penna substantially the same information as that furnished Professor Hartt, and given in Dr. White's Contributions, p. 9. Snr. Penna assured me, however, that he had never seen these rocks exposed elsewhere than at the mouth of the Rio Piábas where they are uncovered at low tide. He found the exposure while making a trip along the coast in a small boat, and spent but a few minutes in making the collection from which Dr. White describes so many species.

*Rio São Francisco above the Falls of Paulo Afonso.*—The secondary nature of some of the rocks of the São Francisco valley above the falls was first made known

\* Edinburgh New Philosophical Jour., Jan., 1841.

† A Contribution to the Vertebrate Paleontology of Brazil. By E. D. Cope. Proc. Am. Phil. Soc., January, 1886, pp. 1-21. The opinion of Dr. Newberry is quoted as here cited. It should be stated, however, that there is possibly a mistake in crediting him with this opinion, for in a recent conversation with the writer, Dr. Newberry referred to these fossils as of cretaceous age.

by Mr. Derby in his article published in the *Archivos do Museu Nacional*, Vol. IV, for 1879 (published in 1881). These are horizontal beds exposed in the isolated hills which extend along the left bank of the river from near Piranhas to Itaparíca, but they form more continuous chains from the serra de Tacaratú toward the interior, while what appear to be plateaux of the same rocks stretch away to the south of the river also. In the immediate neighborhood of the river they are continuous from near the mouth of Pajeú to Itaparíca. Above Pajeú, hills, apparently of these same rocks, stand back from the river and overlie the gneiss. These beds contain silicified wood in abundance, besides a few other fossils. At a place called Atalho, fossil cyprids, bones, teeth, and scales of fishes and of reptiles have been found. At Caissara several leagues further up the river these beds occur again.

The only determination of any of these fossils made by Mr. Derby was that of scales of *Lepidotus*. He ventures the opinion that they are secondary and probably cretaceous, resembling somewhat the fresh-water cretaceous of Bahia.

I regard the discovery of these deposits by Mr. Derby as one of great importance in the study of the mesozoic geology of Brazil, for this locality seems to furnish the facts necessary for the determination of the relations between the coastal beds of the Sergipe-Alagôas region and the interior, and somewhat more elevated, beds of Ceará.

*Rio Purus, Valley of the Amazonas.*—The only unquestionable cretaceous deposits thus far known in the Amazon valley are on the Rio Aquiry, an affluent of the Rio Purús. These deposits were discovered by Chandless and are very briefly described by him in an article published by the Royal Geographical Society, Vol. XXXVI, p. 119 *et seq.* The Aquiry enters the Purús on the right in latitude 8° 45' South, longitude 67° 23' West. From the mouth of this stream to 11° South latitude the water, when low, uncovers rocks in the middle of the stream, in which fossils are found. Vertebræ from these beds were seen by Agassiz at Manáus, and he pronounced them to be those of *Mosasaurus*. Nothing is known of the general character or extent of these beds. The theory that the cretaceous outcrops around the rim of the Amazonian basin is not supported by any known facts.

#### CORRELATION OF THE MESOZOIC OF THE COAST AND THE INTERIOR.

Owing to the lack of knowledge of details a very brief discussion of the relations of the mesozoic beds along the coast with those of the interior is undertaken with much hesitation. Indeed, were it not that this subject has already been touched upon by Mr. Derby in such a manner as to lead geologists to suspect that we have here unusual and very peculiar conditions, it would not be attempted at all.

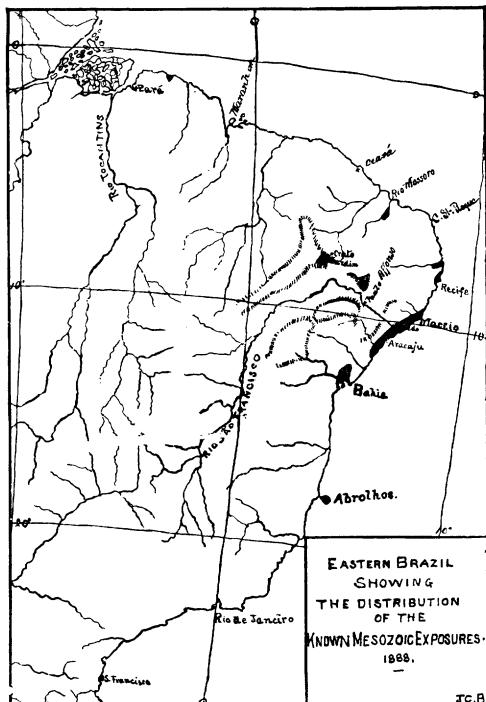
It will be observed upon the small map on this page that, besides the small basins along the Brazilian coast, there are, leaving the Purús exposures out of account, two mesozoic localities at some distance from the coast, one at and about Crato in Ceará, another about Tacaratú, a short distance above Paulo Affonso, in the valley of the Rio São Francisco.

The cretaceous beds of the Sergipe-Alagôas basin overlie paleozoic rocks, those of the São Francisco basin appear to overlie metamorphic rocks, which may be either paleozoic or archæan, while the Ceará beds overlie slates which are probably paleozoic. The region separating the Sergipe-Alagôas exposures from those of the São Francisco basin are granitic and metamorphic, while metamorphic rocks lie between the Ceará exposures and the sea coast. If we take into consideration the cretaceous basin of Bahia we find that also separated from the exposures of the São Francisco basin by crystalline and metamorphic rocks.

Gardner reports fossil fishes in the vicinity of Jardim, a town south-east of Crato. The serra de Tacaratú on the northern side of the Rio São Francisco above the falls of Paulo Affonso is said by Mr. Derby to be composed of rocks of secondary age. This serra is about one hundred miles south-east of Jardim, but Mr. Derby says\* that "these secondary deposits become more continuous and form a long line of hills, which beginning with the serra de Tacaratú stretches away into the interior of the province of Pernambuco." The intervening country has not been examined, but it seems highly probable then that the Tacaratú beds are the southern extension of those of Crato and Jardim.

As nothing is known of the details of the mesozoic geology of the Mossoro basin, nothing can be ventured regarding it further than that its proximity to the Crato exposures naturally suggests that the beds of the two localities are identical, the intervening beds having, in all probability, been removed by erosion.

Mr. Derby intimates that there is something peculiar about the relations of the coastal mesozoic beds to those of the interior. The objection offered by him to the correlation of the Ceará and the São Francisco valley beds with those along the



\* Archivos do Museu Nacional, Vol. IV, p. 92.

coast, namely, that they stand at different elevations, reduces itself to the suggestion of a classification of geological formations by comparative elevations.\* If all the beds of the cretaceous both upon the coast and the interior were found to be perfectly horizontal, with no evidences of faulting between, we might possibly be justified in such an assumption. The position of the Sergipe-Alagôas beds, however, shows that this is not only not the case, but that in this basin, at least, the beds have a very decided dip toward the ocean, while their inland margins rise to a height of from 400 to 500 metres or more where they overlie the paleozoic beds of the Itabaiána. At their inland margins they rise to the same elevation above a large number of exposures of the same beds at tide level near the coast. If no connection had been traced out between these Sergipe localities we should be obliged, according to this hypsometric classification, to separate these beds geologically. This suggestion must be regarded, therefore, as a geological *non sequitur*. Mr. Derby assumes also that the coastal cretaceous beds do not reach an elevation greater than 100 metres above tide. This is erroneous. The serra of Itabaiána is, according to Mouchez, from 700 to 800 metres above tide, and the cretaceous beds overlie the paleozoic beds of Itabaiána to within 150 metres of its summit, which would make the elevation of the cretaceous at this place above tide about 600 metres.

According to the elevations along the Rio São Francisco, determined by Col. W. Milnor Roberts, the river near Tacaratu and in the vicinity of the secondary beds reported by Mr. Derby, is 320 metres above tide, and, according to him, the hills to the north are about 300 metres above their bases,† or, say 620 metres above tide.

The Ceará beds, according to Gardner, rise to an elevation of 600 metres above tide, which would also indicate that, as far as elevations are concerned, there is no important difference between the interior and the highest of the coastal deposits. But I lay no stress upon this elevation of the coastal beds, for, to my mind, it is a matter of but little importance, and I return to my original statement, that even if there were very marked differences of elevation, nothing could be deduced therefrom in regard to the relative geologic ages of the beds of the various localities. The elevation of the Brazilian coast has not been an even one, and there is certainly no reason for supposing that it would be. The elevation or depression of coast lines, and especially of lines as long as that from Rio de Janeiro to the mouth of the Amazon, has seldom or never been known to be even or regular. It is true that the tertiary beds along the Brazilian coast have a generally horizontal position, but this appear-

\* "It is difficult to admit the contemporaneous deposition of beds at such different elevations," Archivos do Museu Nacional, Vol. IV, p. 94.

† Archivos do Mus. Nac., 1879, Vol. IV, p. 91.

ance does not conflict in any respect with the idea of unequal elevation, for this elevation would need to be very unequal indeed to make itself perceptible to the unaided eye.\*

All of the little evidence we have seems to suggest the identity of the coastal with the inland beds—certainly it does not suggest any obstacle to their correlation.

Agassiz pronounced the fossil fishes, collected by Gardner, cretaceous, while Newberry and Cope believe them to be of jurassic age. Dr. White pronounces the majority of the Sergipe-Alagôas fossils to be cretaceous, though he and Prof. Hyatt declare many of them to have a jurassic aspect. If these facts suggest anything in regard to the relations of the rocks to these localities, it is that the probabilities favor their, at least, approximate identity. While I cannot, of course, maintain this correlation, I must, at least, dissent from a separation without better evidence than has thus far been adduced.

\* See Géologie du Brésil, par Emmanuel Liais, p. 249.

## PART III.

## THE TERTIARY.

The thorough understanding of the tertiary geology of Brazil, not to say of South America, would, in my opinion, be of more interest and value to geology than that of any other geologic horizon represented on that continent. A full discussion of it cannot be undertaken here, is not intended, and indeed would be impossible without a vast amount of field work. The formation is too widespread and the questions presented by it too complicated to admit of discussion in this place, further than it relates to the geology of the Sergipe-Alagôas basin and to the cretaceous formations of the eastern coast.

In Brazil this formation is represented by horizontal beds of sands and clays forming a system of marine terraces from 100 to 250 feet thick, extending from somewhere between Rio de Janeiro and Bahia more or less continuously along the coast to the north, being especially prominent from about Maceio nearly to Cape St. Roque. In the Amazon valley they form the table-topped hills and are widespread from the Rio Araguay westward. The beds of the Amazon valley were thought by Agassiz to have been deposited in an inland lake during the glacial epoch. Pissis says that the marine tertiary beds of the coast are represented in the interior by beds of lacustrine origin. The origin attributed to the tertiary by Prof. Agassiz need not be discussed, as in all probability no one now admits its correctness, while a lack of knowledge of the lacustrine deposits of the interior renders the discussion of the theory of Pissis impossible. It must be admitted, however, that this theory of Pissis is a very plausible one, and such observations as the writer has made upon the geology of the interior of Brazil leads him to accept it as a favorite working hypothesis. In none of the supposed tertiary beds of the interior, at least in the provinces of Rio de Janeiro, Minas Geraes and Matto Grosso, has the writer found unquestionable evidence of the tertiary age of such deposits.\*

*Character of the Beds.*—The general features of the Brazilian tertiary have been several times described by such good observers as Agassiz and Hartt. The uniformity

\* Since the above was written a letter, making inquiry concerning the tertiary, has been directed to Mr. James E. Mills, of San Francisco, Cal., who has traveled in many parts of the interior of Brazil. In reply Mr. Mills says: "I cannot give you any definite information from my notes about the tertiary deposits in Brazil, because in Rio Grande do Sul, Minas Geraes, Rio de Janeiro, and other parts of the country where I had opportunities for observations and study, there are no deposits which I know certainly to be of tertiary age."

in its general characters between such widely separated regions as the Amazonas and Sergipe or Bahia is worthy of note. The description by Hartt of the tertiary hills of Parauaquára\* might have been written of some of the Sergipe exposures with the exception of the sequence of the various beds. The following is his section, beginning at the top:

1. A few feet of fine, light, brick-red earth, consisting of a mixture of clay and fine sand.
2. Red sandy clay with iron nodules.
3. Tauatinga clay, grayish-white. Heavy bed, not laminated.
4. White clay, partly pure tauatinga, partly sand, resembling brick of two imperfectly mixed clays. Bakes hard in the sun and resists denudation.
5. White or cream-colored, soft, fine-grained sandstones.
6. Variegated sandy clay.
7. Argillaceous sandstone variegated with bands and mottlings of delicate shades of white, red, purple, brown and yellow.

The following section was observed near Maroim, and may serve as a type of this formation along this part of the coast:

1. Surface soil, sandy,	4 feet.
2. Mottled red and white clays,	3 "
3. Brown sandstone,	1 foot.
4. Chalky above, red beneath,	6 feet.
5. Terra-cotta colored sandy clays,	7 "
6. Dark red, hard clays,	2 "
7. Soft, light-brown sandstone,	3 "
8. Soft white sandstone,	10 "
9. Soft earthy sand,	1 foot.
10. Talus, principally from No. 7,	15 feet.

Not enough attention was paid to the tertiary to enable the writer to say whether the sequence of the beds is at all uniform even within the limits of the Sergipe-Alagoas basin.

*Evidences of the Age of this Formation.*—The series of rocks here referred to the tertiary are so called upon stratigraphic evidence alone, for it is a very remarkable fact in regard to these beds that, widespread as they are, no fossils have ever been found in them, though diligent search was made for them by the writer, and doubtless also by others. But their relations to the cretaceous and their general resemblance to the tertiary beds of other parts of the world scarcely leave any doubt about the

\* Bul. Buf. Soc. Nat. Sci., Jan., 1874.

correctness of this reference. What portion or portions of the European or North American tertiary they represent it is quite impossible to say. In general appearance the deposits bear a strong resemblance to some of the later tertiary formations of the Southern United States, though the materials of the two are derived from very different geologic sources.

*Absence of Fossils.*—It is a peculiar feature of the Brazilian tertiary that with the exception of a few plants found in the Amazon region, fossils have never been discovered in it. That fossils should not be preserved in beds of such thickness and wide distribution, made up of strata of sands and clays variously commingled, is certainly to be wondered at. The statement of the fact has often been questioned, and explained by the assumption that careful search has not been made for them. That they may yet be found is of course highly probable, but the writer has searched miles of exposures in vain for any recognizable trace of organic remains.

Several hypotheses suggest themselves in explanation of the non fossiliferous character of these rocks. After examining the geology of the Amazon region, Agassiz concluded that an enormous glacier once moved down that valley, and built up across its eastern end a gigantic moraine; that as the ice melted the formations which are now believed to be tertiary were deposited from the cold, muddy waters flowing from the glacier into a great lake. This, to his mind, explained also the absence from these beds of organic remains other than leaves. But even if Prof. Agassiz's theory of the origin of these Amazonian beds were accepted\* it would not explain the absence of fossils from the same rocks along the south-eastern coast of Brazil.

Two hypotheses are offered: The first is, that these rocks were deposited so rapidly, and from water so overloaded with mechanically suspended matter, that animal life in them was impossible. It may be said in regard to this theory that while most of the tertiary beds are of a nature which would support it, there are many beds of clays and very fine sands which would hardly be deposited rapidly or from strong currents (see section on p. 410).

The second hypothesis is that these beds once held organic remains, but that they have been dissolved out by infiltrating waters.

*Present Extent of the Tertiary.*—The present distribution of the tertiary beds in the Sergipe-Alagôas basin cannot be given except in general terms, but from the explanation of its relations to the cretaceous rocks of the region (*v. p. 376*) one will

\* Agassiz's theory has never been accepted by the geologists who are acquainted with the geology of the Amazons, and he is said to have abandoned the theory of the glaciation of Brazil before his death. See *Glaciers*, by Shaler and Davis, p. 47.

have no difficulty in knowing what is to be expected. It is much more widespread through the western than the eastern portion of the province of Sergipe, while in Alagôas it is represented by a succession of mutilated terraces. In the western part of Sergipe the dry, thirsty soil of this formation prevents the growth of important forests, and gives to it the name of *agreste* in distinction from the wooded cretaceous soil of the eastern portion.

Near the coast, along the São Francisco river and the other larger streams of the region, there are scarcely any remnants of the tertiary to be seen, but as one recedes from the valleys, outliers of the tertiary become more and more common until it forms continuous taboleiros, deeply gashed at their margins and sometimes abutting unconformably against the paleozoic or cretaceous rocks of the serras. On the sketch map on page 386 the outliers of tertiary in the vicinity of Aracajú and Maroim are located approximately. The tertiary hills are, as a rule, characterized by having flat tops. It not infrequently happens, however, that small outliers have been so extensively eroded that the upper and most resisting bed of clay has been washed away and the lower beds have broken down rapidly, leaving a more rounded and less characteristic topography.

Toward the northern end of the basin the tertiary beds approach nearer and nearer the coast, until, north of Maceió, they form a chain of hills and bluffs which continue with occasional interruptions to near Rio Grande do Norte.

*The Original Extent of the Tertiary.*—The original extent of the tertiary beds is indicated partly by the horizontality and the approximate uniformity in thickness and character of the strata, and, secondly, by the distribution of the existing remnants.

A satisfactory statement of the original limitations is not possible with our present knowledge, because we are ignorant of and have no means of determining the amount of erosion that has taken place from the upper surface of these beds. It is evident, however, from the continuity of the lithological characters of preserved beds where exposed over wide areas, that the strata were originally continuous over the whole of the lower parts of the Sergipe-Alagôas basin, and over many of its considerable elevations as well.

It is easy thus to calculate a part of the erosion that has taken place, but in view of the impossibility of knowing the original thickness of these beds, we cannot make a trustworthy estimate of the whole. It is a noteworthy fact, however, that in the Sergipe-Alagôas basin the remnants of the tertiary beds do not extend beyond the limits of the cretaceous basin into that of the crystalline rocks. They end unconformably against the beds of the Serras d'Itabaiána and Marába, and only

where the cretaceous beds are not limited on their inner margins by such ranges do they rest upon or against the crystalline rocks.

*Denudation.*—The present distribution of the tertiary, the horizontality of its beds, and the high angles of their exposed margins, all go to show that the denudation of these rocks has gone on and is still going on at a rapid rate, whatever the causes. Erosion and denudation are still in progress, and some of the causes, at least, may be studied upon the ground. The tertiary beds frequently form broad, dry, and sterile plateaux or table lands known in Brazil as "chapadas" and "taboleiros." In places these plateaux are almost barren of vegetation, and are deeply scored with gullies, ravines, and gorges as much as two hundred feet in depth. Such spots are quite common about the margins of these plateaux. It is not an uncommon thing, however, for hills having more or less vegetation over them to yield to erosion and to develop such cases as that shown in the accompanying illustration of the "Ruinas de Palmyra," near Cabo Santo Agostinho. This case is a typical one (*v. Plate III*). One is often struck, on looking at these rapidly cutting exposures of tertiary, with their resemblance in miniature to the topography of parts of the Grand Cañon region of the United States.

The great denudation of the tertiary beds is due to the following five principal causes :

- I. The impenetrability of the surface clays.
- II. The sterility of the soil resulting in barrenness of vegetation, and the absence of the protection arising therefrom (*v. p. 376*).
- III. The unresisting nature of the rocks (*v. p. 410*).
- IV. The great precipitation concentrated within a few months of the year increasing in geometric ratio the abrading and transporting powers of the water.

V. The temperature of the water considerably elevated by falling upon the bare hot surface clays.

I shall speak of these causes in their order. (I) The impenetrability of the soil prevents the precipitation from soaking into the ground, obliges it to seek its level along the surface at once and is therefore conducive to floods and to corrosion. The tertiary clay through this region being more or less impenetrable, sheds its water almost perfectly, and thus hastens erosion by floods and freshets whose abrading and transporting powers are enormous.

It will be observed that in almost all the descriptions of Brazilian tertiary sections there are alternate sandy and clayey beds. When erosion acts readily upon the sandy ones they are soon removed until a bed containing sufficient clay to turn the water readily is reached. This bed then becomes the surface clay of the country



"Ruinas de Palmyra," near Cape Sto. Agostinho.

shedding the great precipitation of the region and sending it in powerful torrents down the soft margins of the formation whence enormous quantities of earth are swept away.

(II) The sterility of the soils derived from the tertiary is notorious. This sterility is due largely to the tendency of the surface clays to turn the rainfall instead of allowing the water to soak into the ground. But little water is able to penetrate the ground, and for this reason dry weather is invariably fatal to crops in tertiary soils. The natural vegetation is remarkably scant, except in the deep ravines. The wiry grass, stunted trees, and cacti that grow over these sterile plateaux, or "chapadas" as they are called, offer but little resistance to the water flowing from the surface.

(III) In the description of sections in the tertiary it may be seen that there are no beds in the whole column capable of long resisting the ordinary processes of sub-aerial erosion in the tropics. The beds are usually clays and sands variously commingled. I have seen but one indurated rock in the series—a very hard, glassy quartzite, metamorphosed in weathering, but this rock does not appear to form a continuous bed at any one place, or to occupy a definite position in the series. In such soft and easily eroded material the heavy rainfalls of Brazil do the greatest possible amount of work.

(IV) *Precipitation.*—That precipitation in the tropics is not as evenly distributed through the year as in temperate regions is a well-known fact.

In Brazil the year is divided as naturally into rainy weather, "*tempo de chuva*," and sunny weather, "*tempo de sol*," as in temperate regions it is divided into winter and summer; but it is important to note also that the rainy season is the hot season, the "*tempo de sol*," referring to continuous sunshine.

The rainy season does not set in at the same time in all parts of the country, but may begin one, two or three months later or earlier in one place than in another. This, however, does not affect the general results. One of the best records of rainfall in Brazil of which I have knowledge is that kept by the St. John del Rey Gold Mining Company at Morro Velho, in the province of Minas. This record covers the period from 1855 to the present. A resumé of these observations published in 1880 shows\* the average annual rainfall up to that time to be 1637 millimetres, and that 89 per cent of this, or 1457 millimetres, fell during the six months from October to March inclusive, while from April until September only 180 millimetres fell.

A series of observations kept at the city of São Paulo during the year 1879†

\* See "Relatorio de W. Milnor Roberts sobre o Rio São Francisco," Rio de Janeiro, 1880, and *Revista de Engenharia* for May, 1880.

† *The Rio News*, February 5, 1880.

shows that out of the total rainfall of 1287 millimetres during the year, 1152 millimetres fell from November to April inclusive.

Observations made during 1881 at São Bento das Lages in the province of Bahia give a total precipitation of 1984 millimetres for the year, of which 1439 millimetres fell from March to August inclusive.\*

Observations made at Uberába, province of Minas, from 1880 to 1882 inclusive, show an average annual precipitation of 1561 millimetres, of which 1264 millimetres fell from October to March inclusive.†

Records of the rainfall in Ceará during the twenty-eight years from 1849 to 1876 show an average precipitation of 1346 millimetres during one half the year, against 143 millimetres during the other half.‡

These examples are sufficient to give a correct idea of the distribution in time of the precipitation in Brazil. A rainfall so unevenly distributed cannot fail to do an unusually large amount of erosion.

On the whole, however, the erosion of these tertiary beds does not appear to be going on so rapidly as formerly, and indeed I am not disposed to believe that the extensive denudation of the tertiary beds which has taken place in Brazil is to be attributed to subaerial erosion alone. It seems probable that the greater part of this work was done at the time of and immediately after the emergence of these beds from beneath the ocean, while the beds were even softer than at present, and before the surface was taken possession of by vegetation. In many places over the tertiary region where the country is thickly clad with vegetation, erosion is practically *nil*. The great width of many of the valleys and the precipitous faces of the tertiary ranges that border them suggest that these hills faced the ocean, or were the shores of bays during the time of the land's elevation from beneath the tertiary seas.

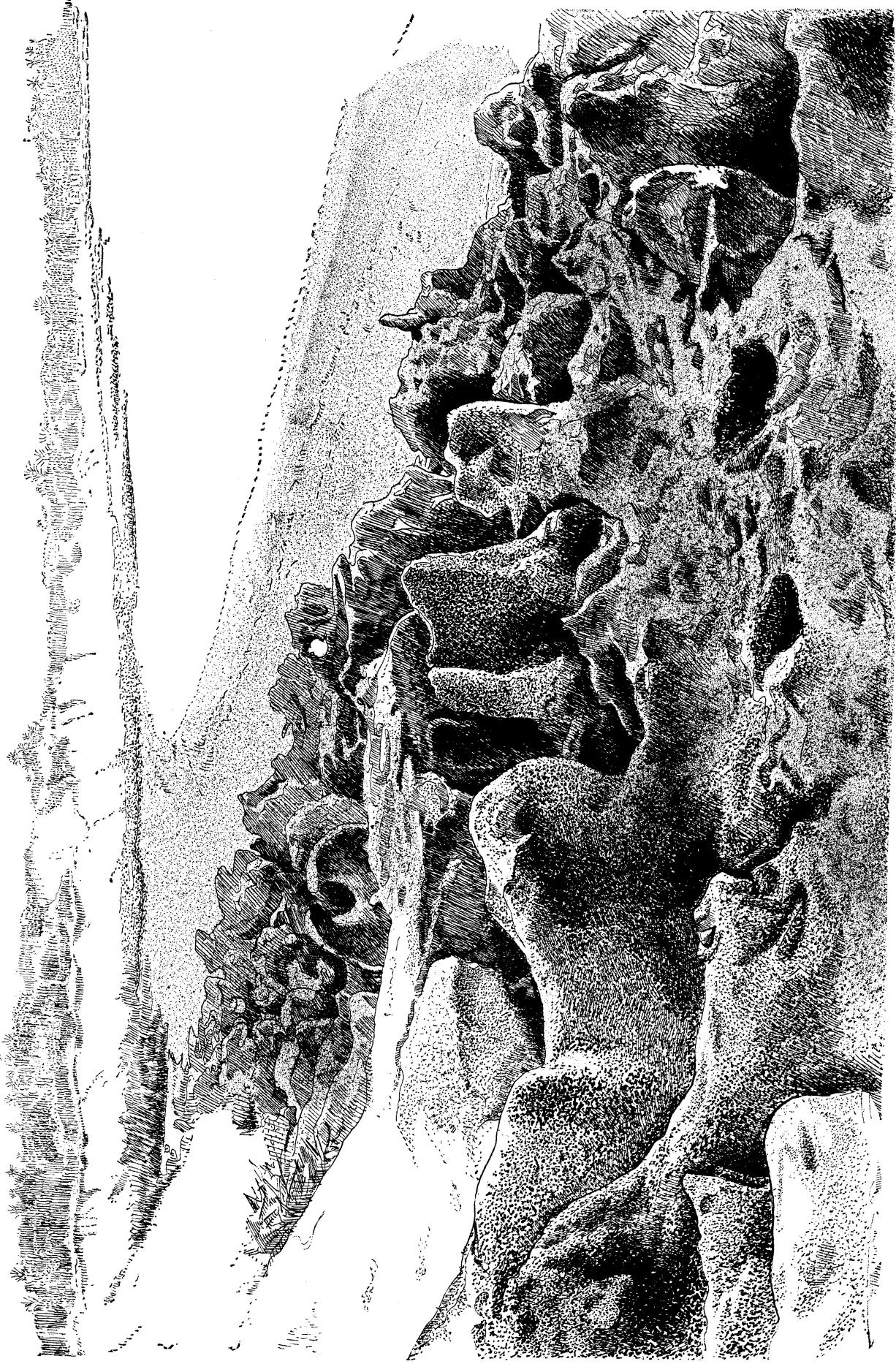
At many places along the Brazilian coast the ocean is also attacking these tertiary beds upon the edges, undermining them and spreading the material of which they are composed over the ocean's bottom. The bed of the ocean north of Rio de Janeiro is, in most places, covered, not with the glauconite ooze usually found along the shores of continents, but for the most part with red mud carried down by the streams, or washed away directly by the waters and undertow from the soft red tertiary rocks of the coast.§ The red cliffs, so noticeable to one sailing along the coast in sight of the shore, are all tertiary, and wherever the water breaks against the bases of these cliffs, they are being rapidly cut away.

\* *V. Revista de Engenharia* for May, 1882.

† *V. Revista de Engenharia*, Vol. V. (1883), p. 251.

‡ *V. Esaios Estatísticos de Pompeu de Souza Brazil*, p. 105 (in part).

§ *V. Challenger Reports; Narrative*, Vol. I, Part I, pp. 215-217.



A Beach of Tertiary Sandstone, Rio Formoso, Province of Pernambuco.

The greater portion of this red mud is derived directly from the cliffs along the shores where the ocean is a more direct agent of erosion, transportation and distribution of this material than the streams themselves. I make this statement advisedly. The streams of the region do not now, as a rule, have sufficient current to be such powerful agents of transportation as they formerly were. In the lower portions of their courses they have generally cut down to or near their base levels, and are therefore comparatively powerless. During the season of rains the finer sediments are washed from high grounds into all the streams, but the Rio São Francisco is the only stream flowing into the ocean in Brazil south of the Amazon, which brings down any considerable quantity of sediment. Such streams as the Sergipe seldom carry muddy waters into the ocean, the material brought in suspension from the higher country being precipitated near the head of tide water, which is usually miles inland.

It happens that nearly all these tertiary beds have already been worn away from the immediate neighborhood of the ocean in the Sergipe-Alagôas basin. They are well exposed, however, along the coast between Maria Farinha and Parahyba in cliffs, some of which are more than four hundred feet in height.

In a few places tertiary beds are exposed along the ocean's beach, having no considerable thickness of their own formation overlying them. In such places they offer more than the usual resistance to the encroachment of the sea, and though the beds are by no means hard, they are worn into fantastic forms by the surf. An example of this kind is shown in the plate illustrating the erosion of a tertiary beach near Rio Formozo in the province of Pernambuco (*v. Plate IV*).

*Horizontality of the Beds.*—These beds are, everywhere I have seen them, so nearly horizontal that no dip is apparent. Exposures have been seen where the beds appeared, at first sight, to have dips as high as twenty degrees, but upon closer inspection they have turned out to be delusive. In other places the writer has seen steep dips caused by the caving and tumbling down from banks of fragments so large that they might easily deceive the observer into believing them true dips. Pissis gives three examples of dips in the tertiary, one of which is as high as  $15^{\circ}$ \* The cases cited are possibly delusive ones, such as are referred to above.

*Metamorphism in the Tertiary.*—The fact that there are compact, glassy quartzites among these tertiary beds might, if taken alone, lead one to surmise that this formation had undergone dynamic disturbances. Such, however, is not the case. These quartzites seldom or never occur forming beds continuous over considerable distances, but are derived from soft beds of sandstone which become indurated here

\* Mémoire sur la position géologique, etc., p. 467.

and there upon exposure, forming quartzite blocks. As the surrounding portions of the beds weather away, these blocks are usually left lying loose on the surface where they exfoliate somewhat under the same influences that hardened them. That this metamorphism is produced by weathering scarcely admits of doubt. The beds which are metamorphosed are high up in the tertiary series, the underlying beds being made up of soft horizontally stratified beds of clays and sands. It is quite evident that these rocks have not been subjected to any unusual lateral pressure, such as that which so often produces metamorphism. The pressure from above is and always has been less than that upon the underlying soft beds of sand, so that its metamorphism cannot be attributed to pressure from above. The strongest evidence that this metamorphism is a process of weathering is found in the condition of some of the partially metamorphosed masses of sandstone. The writer has seen at three separate exposures large masses of this glassy quartzite protruding from banks of soft sandstone, which, upon being broken off two or three feet beneath the face of the exposure, showed the uncovered end of the block to be nothing more than sand in process of hardening, the mass becoming harder and harder toward the exposed surface. When these blocks are entirely separated from their surroundings and lie fully exposed to sunshine and rain, they become as hard as glass and have a similar conchoidal fracture. Heated as they usually are by the direct rays of the sun during the day and cooled by radiation at night or by cool rains, their angles exfoliate until they are almost perfectly round. Prof. Hartt at one time thought that these boulders were brought to this region by glacial action. Although these quartzites are tertiary, there are occasional quartzitic beds in the cretaceous also, yet there is but little danger of confounding them; those of the tertiary being barren of fossils, while those from the cretaceous usually contain a few fossils. The hard cretaceous sandstones in the Riacho de Aroeira approximate in general appearance to the tertiary quartzites. It would not be safe, however, to assign all the non-fossiliferous quartzites of this region to the tertiary, for some of the cretaceous sandstones have been sufficiently porous to allow percolating waters to dissolve out the fossils, and subsequently they have been changed to quartzites. I find in my notes the opinion expressed that a certain bed of quartzite more or less buried beneath black cretaceous limestone soils, is cretaceous, and uncovered by the decay of overlying beds of limestone.

Tertiary quartzites were observed in the Sergipe basin at the following localities:

1. Sitio da Ribeira, on the Rio Sergipe as one ascends the stream from Aracajú towards Pintos, on the north-west side, opposite Andorinhas quarries. These blocks have evidently been derived from beds at a higher elevation and have been left here by denudation.

2. On the hill-tops west of Maroim, and beyond (from the town) the church Maroim de Cima.

3. Fazenda de Sto. Antonio, three-quarters of a mile west of the church. These quartzites are also on the hill-tops.

4. East of Sto. Antonio, and visible from the church of Maroim de Cima is a hill covered with quartzite.

5. Immediately north-west of Maroim on the hill-top, exfoliating in blocks. Along the Estrada Real also north-west of Maroim, a bed one to two feet thick is exposed. The Santa Cruz church north-west of Maroim is on a hill of ferruginous conglomerate, bare of vegetation.

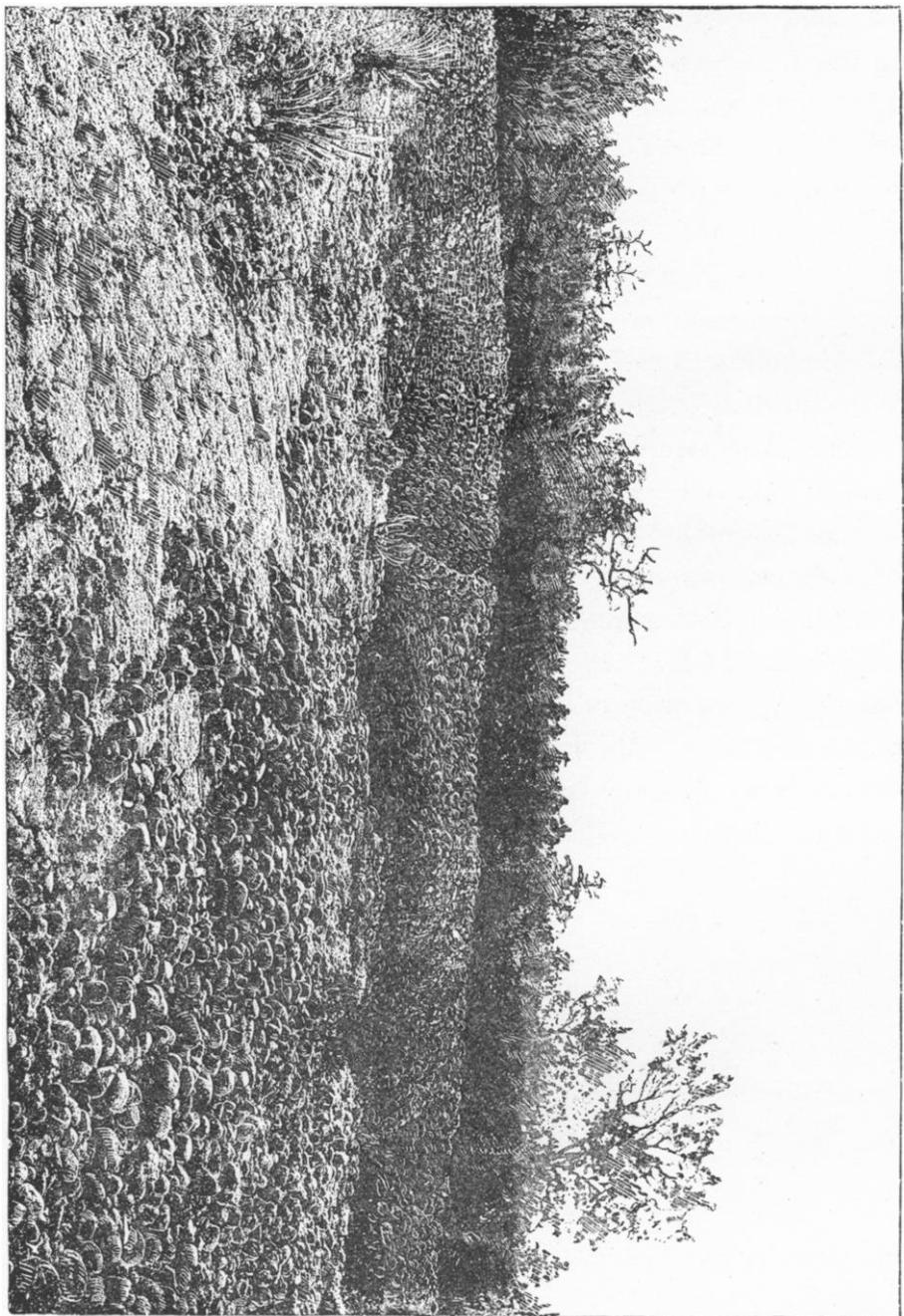
#### SURFACE GEOLOGY.

*Post-tertiary.*—On the hills west of the Cotinguiba at a sitio near Maroim known as Sitio de Belemges, and again along the hills about the Santa Cruz church north-west of Maroim, are types of a formation overlying the tertiary. This formation is spread over the hills and valleys of the Sergipe-Alagôas basin and over the adjacent country in the form of a thin coating of cobblestones, pebbles and sand, sometimes loose and sometimes cemented into a pudding-stone as much as ten feet in thickness, and, when exposed, stained black by manganese. It caps the summits of the tertiary plateaux or their outliers, and it is frequently strewn along down the sides of hills and accumulated in the valleys. It is not confined to the geographic limits of the cretaceous or tertiary, but is found further inland and far beyond the present limits of these formations. It is everywhere more or less irregular in thickness, and nowhere can it be said to be universal or continuous. The writer has seen this material throughout Sergipe and Alagôas, in Parahyba, and as far inland as the headwaters of the Rio Ipanéma in the interior of the province of Pernambuco, where there is no remnant of stratified tertiary beds. Between the lower Rio São Francisco and the frontier of the province of Alagôas, and indeed in many parts of the province of Pernambuco, this water-worn material is found mingled in bogs with the remains of extinct, gigantic mammals.

One of the marked characteristics of this post-tertiary formation is that it is much coarser inland, and grows finer as the coast is approached. The explanation of this water-worn material seems to be that the tertiary period was closed by a depression along the present coast, which carried the beach line far inland, or that it was already there. Then followed a gradual emergence, during which the whole area now covered by this widely distributed water-worn material was passed gradu-

ally through the condition of a beach upon which the then loose, angular, surface rocks of the country were rounded and worn into the boulders, cobbles and pebbles which we now find scattered over this region. While the surf was beating upon and wearing the hard crystalline and metamorphic rocks of the interior it was unable to produce any very marked effect upon the topography of the country, but when, in the course of the land's emergence, the soft, sandy and clayey beds of the tertiary were brought within its reach, the work of land sculpture it was able to do was enormously increased. During the emergence of these tertiary beds they were deeply eroded, and the mud which originally made part of them was washed seaward, and their coarser materials were concentrated upon the slowly receding beach. In some places these accumulations assume unusual proportions, as if they had been brought together by the gradual beating of waves along a beach, or had been reconcentrated by later streams. An example of this kind, outside the Sergipe-Alagôas basin, occurs at the Camassarí diamond washings in the province of Bahia (*v. Plate V.*). It would seem that during this period some of the wider valleys excavated in the tertiary were formed. The concentration of coarse material left spread over the surface of the remaining portions of the tertiary, and indeed over the whole country rising from the bottom of the ocean, the thin covering of cobblestones, and pebbles such as we now have. Later, by the oxidation of the iron in these beds they have been changed here and there to a ferruginous conglomerate.

The post-tertiary deposit is very widespread in Brazil, and has been referred by both Agassiz and Hartt to glacial action.



Diamond Washings of Camassari; Province of Bahia.

## PART IV.

## BIBLIOGRAPHY.

*Bibliography of the Geology of Sergipe-Alagôas Basin.*

ANONYMOUS ARTICLES : A Comissão Geologica do Brazil, published in "O Vulgarisador" newspaper of Rio de Janeiro, Brazil, November 3, 1877.

The same article was reprinted in "O Novo Mundo," an illustrated periodical published in New York, Vol. VIII, January, 1878, pp. 18-19.

The article gives a brief sketch of the region explored and the collections made by the Imperial Survey.

COMSTOCK, T. B.—American Journal of Science, XI, June, 1877, pp. 466-473, contains an abridged report by Prof. Charles F. Hartt upon the work of the Comissão Geologica do Brazil, translated by T. B. Comstock from the report printed in Portuguese. See Hartt, Relatorio Preliminar de Trabalhos da Comissão Geologica na Província de Pernambuco.

DERBY, ORVILLE A.—O Brazil Geographico e Historico ; A Terra e o Homem, por J. E. Wappaeus, Rio de Janeiro, 1884.

This book upon the physical geography, natural history, etc., of Brazil, is the work of several collaborators, the geology (Chap. V, p. 44 *et seq.*) having been written by Mr. Derby. He mentions the provinces in which cretaceous and tertiary formations are found, and gives a small map showing their general distribution, and remarks that the relation between the cretaceous along the coast and that at higher elevations is not known.

DERBY, O. A.—Contributions to the Paleontology of Brazil, by Charles A. White.

The descriptive part of this important work, pp. 7-14, is by Mr. Derby, and is the most important paper yet published upon the stratigraphy of the mesozoic and tertiary geology of Brazil. The leading facts known to him regarding all the Brazilian cretaceous localities, except those of São Francisco do Sul, are given. The theory advanced by Mr. Derby, however, to the effect that the Ceará beds "appear to be a distinct series" because they rise to a greater elevation than other known localities, is criticised on pages 408-410 of the present paper.

DERBY, O. A.—Contribuições para o Estudo da Geologia do Vale do Rio São Francisco, pelo Dr. O. A. Derby, published in the Archivos do Museu Nacional, Vol. IV, 1879, p. 87 *et seq.*

In connection with the geology of the lower São Francisco, Mr. Derby takes occasion to sketch and discuss the cretaceous and tertiary geology of the entire

Brazilian coast. He announces the important discovery of secondary beds at Atalho and Caissara on the São Francisco, above the falls of Paulo Affonso, and expresses the opinion that they extend to the south along that side of the valley.

These beds are said to resemble those of Bahia, but doubt is expressed regarding their being the same, because the author finds it "difficult to admit the contemporaneous deposition of beds at such different elevations."

GARDNER, GEORGE.—Travels in the Interior of Brazil, principally through the Northern Provinces and the Gold and Diamond Districts during the years 1836-1841, by George Gardner, F.L.S., London, 1846, 113-147. There are but few important notes on the geology of Sergipe-Alagôas. On p. 119, he says the rocks at Penedo dip west, which should read east. On p. 198 *et seq.*, he describes the chalk formation of Ceará. This is substantially a repetition, with less detail, of the article from the Proceedings of the Glasgow Philosophical Society, of April, 1843, referred to below.

HARTT, CH. FRED.—Geology and Physical Geography of Brazil, by Ch. Fred. Hartt, Boston, 1870.

This book contains all sorts of valuable scientific information regarding all parts of Brazil. The observations of the writer, who visited Minas Geraes and the provinces along the coast north of Rio, are supplemented by a study of almost all the best authorities regarding the geography, geology and natural history of the Empire, so that the work represents, better than any other, the state of knowledge of Brazilian geology at the time of its publication. Following Agassiz, he refers the surface geology to the glacial drift, gives excellent descriptions of the tertiary at many localities, refers the sedimentary beds of the Abrolhos, and the fresh-water deposits of the Bahia basin to the cretaceous. He touched at Aracajú, Maroim and Penedo, and from Maroim took away a small collection of fossils, which lead him to refer the rocks of the region to the cretaceous. On pages 555 *et seq.* he gives a resumé of the mesozoic geology of Brazil. The name "Sergipian group" is proposed for the limestones of Maroim, and the "Cotinguiban group" for the cream-colored limestones of Sapucary. The work is illustrated with many carefully executed wood-cuts, among which are numerous valuable geological sections.

HENDERSON, JAMES.—A History of Brazil, by James Henderson, London, 1821.

He mentions the occurrence of flints and limestones in the province of Sergipe.

HYATT, ALPHEUS.—Report on the Cretaceous Fossils from Maroim, Province of Sergipe, Brazil, by Alpheus Hyatt. In Hartt's Geology and Physical Geography of Brazil, p. 385 *et seq.*

Five species of fossils, mostly cephalopods, are described from a collection made at Maroim by Prof. Hartt.

HYATT, PROF. ALPHEUS.—The Jurassic and Cretaceous Ammonites collected in South America by Prof. James Orton, with an Appendix upon the Cretaceous Ammonites of Prof. Hartt's collection, by Alpheus Hyatt. Proceedings of the Boston Society of Natural History, Vol. XVII (May, 1875), pp. 365-372, Boston, 1875.

This paper has a brief note upon *Buchiceras harttii* Hyatt, described by him in Hartt's Geology of Brazil, p. 386, as *Ceratites harttii*.

MOUCHEZ, CAPT. ERNEST.—Les Côtes du Brésil, Descriptions et Instructions Nautiques, par M. Ernest Mouchez, Captain de Vaisseau. Première Section. Du Cap San Roque a Bahia, Paris, 1874.

Although this work has nothing directly upon geology, it contains many facts of great value in studying the geology of the northeastern coast, and especially the tertiary of Brazil, which is so intimately connected with the present aspect of the coast in many places. On p. 16 are observations upon the continental shelf; on pp. 20-21, the currents of the coast and tides and reefs are discussed, while the elevations of a great many points along the coast are given. On p. 145, he says that gold and diamonds are found in Itabaiána, and speaks of a great quantity of "*tourbe combustible*" and the probability of coal being found, and adds that "Cette province est également célèbre par les richesses fossiles qu'on y rencontre, principalement sur les bords du São Francisco."

WHITE, CHARLES A.—Contribuições á Paleontologia do Brazil (com o original em inglez), por Charles A. White, M.D. Archivos do Museu Nacional, Vol. VII, Rio de Janeiro, 1887.

An extract from the Archivos was made of this paper and issued with an announcement and "errata," by Dr. White, from Washington, D.C., dated January 2, 1888, under the title, "Contributions to the Paleontology of Brazil; Comprising Descriptions of Cretaceous Invertebrate Fossils, Mainly from the Provinces of Sergipe, Pernambuco, Pará and Bahia."

This work is by far the most important one ever published upon the paleontology of Brazil. The bibliography of the invertebrate mesozoic paleontology of South America is given, followed by a brief but comprehensive sketch of the mesozoic geology of Brazil, by Mr. Derby.

315 species of mesozoic fossils are described, 170 of which are new. These include the lamellibranchs, gasteropods, cephalopods and echinoderms, collected by the Imperial Geological Survey in the provinces of Sergipe, Bahia, Pernambuco and Pará. All are accompanied by excellent plates of 445 figures, drawn by McConnell and lithographed by Sinclair, of Philadelphia. In a discussion of the geologic age of the Sergipe beds, Dr. White concludes that, in spite of the jurassic facies of several of the fossil forms, the burden of testimony favors the reference of these beds to the cretaceous.

*Bibliography of the Cretaceous and Tertiary Geology of Brazil bearing upon that of the Sergipe-Alagôas Basin.*

The mesozoic and tertiary geology of Brazil is so intimately connected with that of the other portions of South America that the bibliography of one portion must of necessity include much of that of the other. For this reason some titles are given

here which do not relate directly to the mesozoic or tertiary geology of Brazil. There are besides many valuable works upon the geology of the River Plate basin, the west coast and north-eastern South America, by such writers as Darwin, D'Orbigny, Burmeister, Castelnau, Humboldt and Spix and Martius, to which one naturally turns for trustworthy information in studying the geology of the continent. With the exception of the publications of Spix and Martius, which the writer has been unable to consult carefully, the most pertinent of these works are referred to, the others are omitted. The titles given under the preceding head must, of course, be added to this list.

AGASSIZ, LOUIS.—Edinburgh New Philosophical Journal for January, 1841. Description of the Fossil Fishes Collected by George Gardner in the Province of Ceará, by Louis Agassiz.

Prof. Agassiz referred the beds from which they were taken to the cretaceous.

AGASSIZ, LOUIS.—The Atlantic Monthly (Boston, Mass.) for July and August, 1866. Physical History of the Valley of the Amazon, by Louis Agassiz.

In this article the author expresses the opinion that Ceará and the region north of that province belong geologically to the Amazon Valley region, describes briefly its tertiary deposits, and refers them "to the ice period in its earlier or later phases."

To explain its aqueous origin, he postulates a gigantic terminal moraine closing the valley at its eastern end, behind which these beds are supposed to have been deposited in cold fresh water.

AGASSIZ, PROF. LOUIS.—Geological Sketches, by Louis Agassiz. Boston, 1886, Vol. II, p. 153 *et seq.*

The chapter on the "Physical History of the Valley of the Amazons" is the same as that published under this title in the *Atlantic Monthly* for July and August, 1866.

AGASSIZ, LOUIS AND MAJOR JOÃO MARTINS DA SILVA COUTINHO.—Sur la Géologie de l'Amazone, par MM. Agassiz et Coutinho, Paris, E. Biot, 1867, 8. Extrait du Bulletin de la Société Géographique de France.

Substantially the same views are here given as are published in the *Atlantic Monthly* article referred to above.

AGASSIZ, PROF., AND MRS. LOUIS.—A Journey in Brazil, by Prof. and Mrs. Louis Agassiz, Boston, 1868.

On pp. 146-7, are remarks by Prof. Agassiz upon the so-called glacial drift at Bahia, Pernambuco, Maceio, Parahyba and Pará. He refers to the fossils found at Parahyba do Norte, and he discusses the so-called drift phenomena of the Amazon Valley region. The clays and sands referred to here as glacial drift are tertiary, and the water-worn material found at the places referred to is the "wash," or concentrated coarse material left scattered over the region, as the land rose from beneath the ocean at the close of the tertiary.

AGASSIZ, PROF. LOUIS.—*Comptes Rendus de l'Academie Francaise*, Vol. XVIII, p. 1007.

Letter from Louis Agassiz to Élie de Beaumont describing the fossil fishes from Ceará. Seven species are mentioned by him, and he affirms his belief in the cretaceous age of the Ceará rocks.

ALLEN, J. A.—Notes on the Geological Character of the Country between Chique-Chique, on the Rio de São Francisco and Bahia, Brazil, by J. A. Allen. In Hartt's Geology and Physical Geography of Brazil, pp. 309-318.

A brief but very important contribution to the geology of Eastern Brazil. The author does not attempt to give the horizons of the geological formations found upon his trip, but his descriptions enable one acquainted with the geology of the country to assign them to their various equivalents along the coast.

ALLPORT, S.—On the Discovery of Some Fossil Remains near Bahia in South America. *Quar. Jour. Geol. Soc., London*, Vol. XVI, Pt. III, pp. 263-268.

The article is illustrated, and, besides a brief description of the eastern portion of the Bahia basin about Montserrat and Plataforma, is accompanied by notes on the fossils by John Morris and Prof. T. Rupert Jones. The vertebrate remains described by Mr. Allport are figured in four plates.

ANONYMOUS.—Annual of Scientific Discovery for 1866-7, pp. 270-3.

Agassiz's Lowell Institute lectures are quoted as to the glacial origin of the tertiary of the Amazon.

ANONYMOUS.—Annual of Scientific Discovery for 1871, pp. 246-7.

These notes appear to have been taken from Prof. Hartt's writings. It is stated that the cretaceous beds probably underlie the tertiary of the whole Amazon Valley.

BATES, HENRY WALTER.—*The Naturalist on the Amazons*, by Henry Walter Bates. 4th ed., London, 1875.

A few notes are given in this work concerning the table-topped hills of Almeyrim and the serras north of that point, and upon the parti-colored cliffs about Obidos.

BROWN, C. BARRINGTON.—Tertiary Deposit of the Solimões and Javary Rivers in Brazil, by C. Barrington Brown, with an Appendix by R. Etheridge. *Quarterly Journal of the Geological Society*, February, 1879.

Reference is made to the old loess-like river deposits, and several sections of the tertiary are given. Noting that the tertiary had already been traced from Loreto, Peru, to Tabatinga, the author says that he has not seen this terrane further east than São Paulo, 150 miles below Tabatinga and 1350 miles from the mouth of the Amazon. It is suggested that the tertiary beds have been disturbed. They are said to occupy here an area of 300 miles in length by 50 in breadth, and contain both fresh and brackish water shells.

BROWN, C. BARRINGTON.—On the Ancient River-deposit of the Amazony, by C. Barrington Brown. *Quart. Jour. Geol. Soc.*, Vol. XXXV, 1879, p. 763 *et seq.*, with illustrations.

This paper treats principally of quaternary and recent deposits, but some references are made to the tertiary, while the sections given indicate its relations to the later formations.

BURMEISTER, H.—*Description Physique de la République Argentine d'Apres des Observations personnelles et étrangères*, par le Dr. H. Burmeister, Paris, 1876, 3 vols.

The third volume is dated Buenos Ayres, 1879. This work is a translation from the German. The second volume is upon the geology of the Republic, and the third upon the living and extinct vertebrates. It contains no references to the mesozoic geology of Brazil, but it is useful in connection with its study.

CALDCLEUGH, ALEXANDER.—Travels in South America, during the years 1819–21, etc., by Alexander Caldcleugh, 2 vols., London, 1825.

In Vol. I, p. 48, he refers to the discovery of vertebrate remains, apparently quaternary, near Rio das Contas in the province of Bahia.

CAPANEMA, GUILHERME S. DE.—*Trabalhos da Comissão Scientifica de Exploração*, Part I, Rio de Janeiro, 1862. Secção Geologica, pp. 120–143, by Guilherme S. de Capanema.

This commission was made up exclusively of Brazilians, and extensive explorations were undertaken. Dr. Capanema was chief of the geologic section. He visited Nazareth and the island of Itaparica in Bahia, Parahyba and Ceará. He speaks of the cretaceous rocks at Parahyba, hitherto unknown, and says that the cliffs at Crato, said by Gardner to be chalk, are silicate of alumina.

CHANDLESS, W.—Notes on the River Aquirí, the Principal Affluent of the River Purús, by W. Chandless. *Jour. Roy. Geog. Soc.*, Vol. XXXVI, 1866, p. 119 *et seq.*

The geology of the region treated of is only incidentally referred to in this article. The localities are mentioned from which were taken silicified woods, the remains of *Mosasaurus*, and of extinct turtles.

COMSTOCK, T. B.—American Journal of Science, 1876, pp. 464–6. Note by T. B. Comstock upon the Work of the Comissão Geologica do Brazil.

This note refers principally to the work done by the Brazilian Survey in the Amazon Valley.

COPE, E. D.—A Contribution to the Vertebrate Paleontology of Brazil, by E. D. Cope. *Proceedings of the American Philosophical Society*, Vol. I, No. 121, January, 1886, pp. 1–21.

Descriptions of mesozoic fossils from Bahia, Sergipe and Pernambuco. In this paper Prof. Cope attempts to correlate the Brazilian mesozoic beds with those of the United States. The occurrence of the teeth of one species of fishes (*Apocopodon*

*sericeus* Cope) induces him to believe the Maria Farinha beds of Pernambuco the probable equivalents of the Fox Hills of the United States, or to the Mæstrichtian cretaceous age. Another species from Sapucary leads him to say (p. 7) that these rocks "probably belong to the cretaceous." One species from the north-eastern part of the province of Bahia leads him to refer those rocks to the pliocene-pampæan.

COUTINHO, JOÃO MARTINS DA SILVA.—L'Embouchure de L'Amazone, par Don João Martins da Silva Coutinho. Bulletin de la Société de Géographie, Paris, Octobre, 1867.

The statement is made that the same geology (the tertiary) prevails from the mouth of the Huallagua in Peru to Marajó and to Piauhy.

DARWIN, CHARLES.—Geological Observations on the Volcanic Islands and Parts of South America Visited During the Voyage of H. M. S. "Beagle," by Charles Darwin, M.A., F.R.S., etc., London, second edition, 1876.

Though there is but little in this book which deals directly with the mesozoic and tertiary geology of Brazil, Chapter VIII, upon the elevations of the eastern coast of South America; Chapter XI, on the formation of the Pampas; Chapter XII, upon the older tertiary of Patagonia and Chile, are rich in suggestions which must be kept constantly before the mind in studying the cretaceous and tertiary of Brazil. Appendices to the second part of the volume contain descriptions of secondary and tertiary fossils from South America.

DERBY, O. A.—A Bacia Cretacea do Bahia de Todos os Santos, por Orville A. Derby, M.S. Archivos do Museu Nacional, Vol. III, third and fourth Trimesters, Rio de Janeiro, 1878, pp. 135-158.

In this memoir Mr. Derby brings together all the observations made, up to the time of publication, upon the fresh water cretaceous basin of Bahia, and the accompanying tertiary and crystalline beds. Inasmuch as Mr. Derby has done more work upon this particular region than anyone else, his paper is the most comprehensive yet published. Its value has now been greatly increased by the publication of Dr. White's Invertebrate Paleontology of that basin. The article is in Portuguese, and has never been published in any other language.

DERBY, O. A.—Revista de Engenharia (Rio de Janeiro), Vol. III (1881), Nos. 6, 8, 9, 11, 12. Reconhecimento Geologico do Valle do São Francisco, por Orville A. Derby, M.S.

The article published in the Archivos do Museu Nacional, Vol. IV, 1879, p. 87 *et seq.*, has all the geological facts more fully discussed.

DERBY, O. A.—A Contribution to the Geology of the Lower Amazonas, by Orville A. Derby, M.S. Proceedings of the American Philosophical Society, Vol. XVIII, 1879, pp. 155-178.

The known cretaceous localities of the Amazon region are mentioned and briefly described on pp. 174-5; the tertiary on pp. 176-7. A Portuguese version of this paper is also published in the Archivos do Museu Nacional, Vol. II, 1877, pp. 77-104,

under the title: Contribuições para a Geologia da Região do Baixo Amazonas, pelo Prof. Orville A. Derby, M.S.

D'ORBIGNY, ALCIDE.—Voyage dans les deux Amériques, publié sous la direction de M. Alcide D'Orbigny, Paris, 1859.

Several references to Brazilian geology are made for pp. 120–185, but as this book was intended for a popular work of travels, it contains nothing of importance upon geology. On p. 185, it is remarked, however, that “le calcaire s'y trouve en beaucoup d'endroits.”

D'ORBIGNY, ALCIDE.—Voyage dans l'Amérique Méridionale, Géologie et Cartes, Paris, 1842.

The only maps referring to Brazilian cretaceous and tertiary geology are included in Plate X, Figs. 1, 4 and 5. The text in which these general charts are explained relates mainly to the geology of the River Plate basin, Patagonia and the West Coast. Though this publication represents a great deal of valuable geological details, it contains a vast amount of speculation which, as far as Brazil is concerned, is of doubtful value. There is nothing directly upon the Brazilian cretaceous and tertiary, but the latter portion of the work, pp. 209 *et seq.*, “considérations générales sur la Géologie de l'Amérique Méridionale,” discusses the dynamic movements and building up of the continent. Of the cretaceous terranes, he says (p. 238): “Qu'ils sont tout à fait inconnus aux régions orientales et centrales de l'Amérique Méridionale.” The mesozoic and tertiary geology of Brazil can best be understood by a study of that of the central and western parts of the continent, which he treats at some length, in the Géologie and Paléontologie of his voyage. On p. 237, he discusses the existence of the jurassic in South America.

D'ORBIGNY, ALCIDE.—Comptes Rendus de l'Académie des Sciences, 1842, Vol. XV, p. 771. Considérations générales et coup d'œil d'ensemble sur les grands faits géologiques dans l'Amérique Méridionale a été le théâtre, par Alcide D'Orbigny.

The conclusions of this brief paper are highly imaginary.

DURAND, L'ABBÉ.—Considérations générales sur l'Amazone, par l'Abbé Durand. Bul. de la Soc. de Géographie, Paris, Novembre, 1871.

It is stated that the tertiary seems to be entirely wanting in the Amazon basin; that the bottom of the basin is cretaceous, overlain by from seven to forty metres of clays, above which is a formation of sands, clays and gravels, which are referred to the “trias ou terrain de vieux grès rouge.” A very wide distribution is attributed to this formation.

ETHERIDGE, R.—Notes on the Mollusca collected by C. Barrington Brown from the Tertiary Deposits of Solimões and Javary Rivers, Brazil, by R. Etheridge. Quart. Jour. Geol. Soc., XXXV, 1879, p. 82.

An appendix to Mr. Brown's paper, *q. v.*, consisting of specific descriptions of tertiary fossils.

GARDNER, GEORGE.—Geological Notes made during a Journey from the Coast into the Interior of the Province of Ceará, in the North of Brazil, embracing an Account of a Deposit of Fossil Fishes, by George Gardner, Esq. Edinburgh New Philosophical Journal, April, 1841, p. 75 *et seq.*

HARTT, CH. FRED.—The American Naturalist, Vol. II, March, 1868, No. 1. A Naturalist in Brazil, by Ch. Fred. Hartt.

Brief description and illustrations of the geology of the Abrolhos. The same is given more fully in the author's larger work upon the Geology and Physical Geography of Brazil.

HARTT, CH. FRED.—On the Growth of the South American Continent, by Ch. Fred. Hartt. The Cornell Era (Ithaca, N. Y.), December 12, 1868.

This paper deals with the dynamic movements of the continent, and gives the general order and distribution of the various formations.

HARTT, PROF. CH. F.—Amazonian Drift, by Prof. Ch. F. Hartt. American Journal of Science, April, 1871, pp. 294–296.

The writer expresses the opinion that the horizontally bedded sandstones and clays of the Amazon region referred by Agassiz to glacial drift are tertiary.

HARTT, PROF. CHARLES FRED.—On the Tertiary Basin of the Maranon, by Charles Fred Hartt. American Journal of Science, Vol. IV, July, 1872, pp. 53–58.

This article deals with the tertiary beds of the Upper Amazon region.

HARTT, CHAS. FRED.—Recent Explorations in the Valley of the Amazonas, by Chas. Fred. Hartt. Journal of the American Geographical Society, New York, Vol. III, 1872, pp. 231–252.

The then known extension of the cretaceous in the Amazon Valley is mentioned, and there are a few notes upon the tertiary. The author reiterates his belief in the tertiary age of the Serras of Parú.

HARTT, CHAS. FRED.—Preliminary Report of the Morgan Expedition, 1870–71. Report of a Reconnoissance of the Lower Tapajos, by Chas. Fred. Hartt. Bulletin of the Cornell University (Science), Vol. I, No. 1, Ithaca, N. Y., 1874, pp. 1–37.

This paper sketches the work done by the Morgan Expedition, and contains a few unimportant references to the tertiary beds in the Lower Amazon region.

HARTT, CH. FRED.—Contributions to the Geology and Physical Geography of the Lower Amazonas, by Chas. Fred. Hartt. Bulletin of the Buffalo Society of Natural Science, January, 1875, pp. 201–235.

Contains good descriptions and sketches of the tertiary geology of the Lower Amazonas.

HARTT, CHARLES FRED.—Relatorio Preliminar dos Trabalhos da Comissão Geologica na Província de Pernambuco, por Ch. Fred. Hartt, Chefe da mesma Comissão, Rio de Janeiro, 1875.

This paper contains a few brief notes upon the cretaceous geology of the province of Pernambuco.

HUMBOLDT, ALEXANDER VON.—Personal Narrative of Travels to the Equinoctial Regions of the New Continent during the years 1799-1804, by Alexander Von Humboldt and Aimé Bonpland (English translation from the original French), third edition, London, 1822.

Humboldt and Bonpland did not enter Brazil, and their observations upon the geology of adjacent territory are referred to as valuable supplementary material in the study of the geology of Brazil.

JONES, T. RUPERT.—Note on the Fossils Entomostraca from Monserrate (Bahia), by T. Rupert Jones. Proc. Geol. Soc., Vol. XVI, p. 266.

Descriptions of five species of Cypridæ are given, and Prof. Jones says that they appear to be allied to the recent and tertiary species. This note is a part of an article by S. Allport, on the cretaceous fossils of Bahia. See under Allport.

LIAIS, EMMANUEL.—Climats, Géologie, Faune et Géographie Botanique du Brésil, par Emmanuel Liais. Paris, 1872.

The author of this book traveled extensively in Brazil, and his remarks upon the geology of that country represent much personal observation. For many of his statements, however, he gives no authority. Here and there discussions of the geology of the entire South American continent and correlations of terranes of widely separated regions are attempted. Chapter V is devoted to the discussion of secondary geology, and Chapter VI to that of the tertiary and quaternary. On p. 186, he says that fossils collected by M. Meyen from a locality on the west coast of South America and studied by Von Buch contained both cretaceous and jurassic species. Much doubt as to the value of the book is caused by a considerable number of serious errors. What appear to be facts of great value are so interwoven with figments of the imagination that, to those best acquainted with the geology of Brazil, it does not merit the confidence one would like to give it.

MARSH, PROF. O. C.—Notice of Some New Reptilian Remains from the Cretaceous of Brazil, by Prof. O. C. Marsh. American Journal of Science, May, 1869, pp. 390-392.

These fossils are from the Bahia basin, and include *Crocodilus*, *Thoracosaurus*, *Megalosaurus*. *Lepitodus* scales are reported.

MORRIS, JOHN.—Note on the Molluscan Remain from Monserrate (Bahia). Quart. Jour. Geol. Soc., London, Vol. XVI, p. 266.

This note, containing the description of one species of *Melania*, is part of an article by Allport. See under Allport.

PEREIRA, FELIPPE FRANCISCO.—Roteiro da Costa do Norte do Brazil desde Maceio ate Pará, por Felipe Francisco Pereira, Pernambuco, 1878.

This work contains geographical notes of value in this connection. The hills described and figured along the immediate coast between Maceio and Pará are nearly all tertiary, except that of Cape Santo Agostinho, which is of igneous origin.

PİSSIS, M. A.—Mémoire sur la position Géologique des Terraine de la Partie Australe du Brésil, et sur les Soulèvements qui, à Diverses Époques, ont Changé le Relief de cette Contrée, par M. A. Pissis (présenté à l'Académie das Sciences le 27 Juin, 1842).

This paper relates mostly to the geology of the crystalline rocks of Rio de Janeiro, São Paulo and Minas Geraes. On pp. 397–8, he speaks of the tertiary along the coast between Rio and Bahia, and on pp. 398–9, on the Bahia basin.

In the plates accompanying this memoir, he gives a section at Monserrate, Bahia, while his geological map represents the Bahia fresh water cretaceous basin as tertiary, with a fresh water division covered by marine beds. On this point, see Mr. Rathbun's paper upon the geology of Ithaparica. On p. 403 *et seq.*, he discusses the “grands mouvements du sol” and gives a list of dips. Of the tertiary, he says that the marine tertiary of the coast is represented by lacustrine beds in the interior.

POMPEO DE SOUZA BRAZIL, THOMAZ.—Ensaio Estatística da Província do Ceará, por Thomaz Pompeo de Souza Brazil, 1863.

This work mentions, besides a list of minerals found in the province, the occurrence of cretaceous and quaternary fossils at a number of places (pp. 144–160).

PORTO SEGURO, VISCONDE DE.—Historia Genal do Brazil antes de sua Separação e Independencia de Portugal, pelo Visconde Porto Seguro, Rio de Janeiro, without date. Two vols.

In Vol. I, p. 353, it is stated that the location of the city of Parahyba was fixed by the existence there of a calcareous sandstone, which is in places a true limestone and in others marble.

RATHBUN, RICHARD.—Sketch of the Life and Scientific Work of Prof. Charles Fred. Hartt, by Richard Rathbun. Proceedings of the Boston Society of Natural History, Vol. XIX, pp. 238–364, 1878.

A list is given of the localities at which cretaceous, tertiary and post-tertiary rocks occur. A brief sketch is given of the work accomplished by the Comissão Geologica do Brazil, under Prof. Hartt, and of the geological structure of the various regions explored.

RATHBUN, RICHARD.—Observações sobre a Geologia da Ilha de Itaparica na Bahia de Todos os Santos, por Mr. Richard Rathbun. Archivos do Museu Nacional.

This paper deals with the geology of the island mentioned, but comparisons are made with the geology of the mainland. Most of the paper is occupied with a description of the reefs.

RATHBUN, RICHARD.—Preliminary Report on the Cretaceous Lamellibranchs Collected in the Vicinity of Pernambuco, Brazil, by Richard Rathbun. Proceedings of the Boston Society of Natural History, XVII, 1874, pp. 241–256.

This paper describes twelve new species of Lamellibranchs of the collection made in 1870 by the Morgan expedition, under Prof. Hartt. The prefatory portion of the

paper contains brief notes upon the stratigraphic geology, which are credited to the notes of Mr. Derby.

READE, T. MELLARD.—Denudation of the two Americas, by T. Mellard Reade, C.E., F.G.S. American Journal of Science, Vol. XXIX, No. 172, April, 1885, pp. 290–300. Substance of Presidential Address to the Liverpool Geological Society, Session 1884–5.

A part of this paper is devoted to the rate of denudation of the Amazon basin, and references are made to the nature and distribution of the rocks.

SAMPAIO, THEODORO FERNANDES.—*Revista de Engenharia*, Vol. VI (1884), pp. 52–54. Informações a respeito dos caracteres geologicos do territorio comprehendido entre a cidade de Alagoinhas e a do Joazeiro, por Theodoro Fernandes Sampaio.

Short but valuable notes upon the geology of the region along the railway line from Alagoinhas to the Rio São Francisco. The second chapter treats of the tertiary region, which is said to extend from Alagoinhas to Agua Fria, a distance of fifty-six kilometres.

SMITH, HERBERT H.—Do Rio de Janeiro a Cuyaba. Notas de um Naturalista, por Herbert H. Smith, Rio de Janeiro, 1887.

Reference is made, pp. 10–11, to the evidences of the elevation of the eastern coast of Brazil (Rio) during the quaternary.

WILLIAMSON, E.—On the Geology of the Parahyba and Pernambuco Gold Regions, by E. Williamson. Transaction of the Manchester Geological Society, Part VII, Vol. VI.

This paper is devoted to the occurrence of gold and to the geology of the crystalline and metamorphic rocks of the region. A valuable note is given on the limestones and the tertiary beds which cover them.

WOODWARD, HENRY.—The Tertiary Shells of the Amazon Valley, by Henry Woodward. From the Annals and Magazine of Natural History, for January and February, 1871.

—Challenger Reports. Narrative, Vol. I, Part I, p. 215–217.

The soundings and dredging along the Brazilian coast indicate that the ocean's bottom is here remarkable for the absence of animal remains and glauconite, and that it is covered by fine red mud (pp. 215–217).